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September, 1930

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WE WILL EXHIBIT NATIONAL METAL EXHIBITION, STEVENS HOTEL, CHICAGO, SEPTEMBER 22-26, 1930

JOURNAL

of the

AMERICAN WELDING SOCIETY

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AMERICAN WELDING SOCIETY
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PROGRAM
FALL MEETING

of the

AMERICAN WELDING SOCIETY

September 22, 23, 24, 25 and 26, 1930

CONGRESS HOTEL, CHICAGO, ILL.

IMPORTANT NOTICE

Members and guests are requested to register, as admission to Exposition and some of social events will be by badge only.

ALL Technical Sessions and Committee Meetings will be held at the CONGRESS HOTEL.

ALL sessions start promptly as scheduled.

MONDAY, SEPTEMBER 22

Morning

10.00 a. m. Registration (Florentine Foyer).

Facilities will be provided throughout the week from 9.00 a. m. to 5.00 p. m., commencing Monday, Sept. 22, at 10.00 a. m.

Afternoon

2.00 p. m. Meeting Structural Steel Welding Committee (Room 1164).
Presiding Officer—To be announced.

3.45 p. m. Meeting American Bureau of Welding (Room 1164).
Presiding Officer—C. A. Adams, director, A. B. W.

Evening

6.00 p. m. Dinner Meeting, Board of Directors (Suite 1102-6).
Presiding Officer—E. A. Doyle, president, A. W. S.

TUESDAY, SEPTEMBER 23

Morning

10.00 a. m. Business Session (Florentine Room adjoining Registration Foyer).

Presiding Officer—E. A. Doyle, president, A. W. S.

This will be in the nature of a few introductory remarks by President Doyle; address of welcome by Richard M. Wolf, Commissioner of Public Works, City of Chicago; and transaction of formal business.

Response by C. A. McCune, general chairman, 1930 Fall Meeting and Exposition.

10.30 a. m. Technical Session (Florentine Room adjoining Registration Foyer).

Presiding Officer—J. J. Crowe, member of Executive Committee, A. W. S.

"Welding of Stainless Steel," by L. W. Hostettler, Allegheny Steel Company.

"Arc Welding of Aluminum," by W. M. Dunlap, Aluminum Company of America.

"Oxy-Acetylene Welding of Corrosion Resisting Steels," by W. B Miller, Union Carbide and Carbon Research Laboratories.

Afternoon

2.00 p. m. Technical Session (Florentine Room adjoining Registration Foyer).

Presiding Officer—F. T. Llewellyn, past president, A. W. S.

"The Examination of Welds by the X-Ray Diffraction Method," by J. T. Norton, Massachusetts Institute of Technology.

"Fatigue Investigations of Welded Joints," by G. E. Thornton, State College of Washington.

"Stress Distribution in Side-Welded Joints," by Walter H. Weiskopf and Milton Male. A mathematical study in connection with tests made at the University of Pittsburgh.

WEDNESDAY, SEPTEMBER 24

Morning

10.00 a. m. Technical Session (Florentine Room adjoining Registration Foyer).

Presiding Officer—E. A. Doyle, president, A. W. S.

"Resistance Welding of Bar Joists," by Frank Burton, Steel Joist Institute.

"Cost of Using Welding," by Robert E. Kinkead, consulting engineer.

"Strength of Welded Joints in Tubular Members for Aircraft," by H. L. Whittemore, U. S. Bureau of Standards.

Afternoon

2.00 p. m. Technical Session (Florentine Room adjoining Registration Foyer).

Presiding Officer—H. L. Whittemore, member, Committee on Standard Tests for Welds.

SYMPOSIUM ON TESTING OF WELDS

1. Introduction and Suggested Revision of A. B. W. Bulletin No. 1, by A. B. W. Committee on Standard Tests for Welds.
2. Tensile Tests for Welds—J. W. Owens.
3. Bend Tests for Welds—W. B. Miller.
4. Shear Tests for Welds—Andrew Vogel.
5. Fatigue and Impact Tests for Welds—C. H. Jennings.
6. Use of Gamma Rays for Examining Welds—R. F. Mehl, G. E. Doan and C. S. Barrett.

THURSDAY, SEPTEMBER 25

Morning

9.30 a. m. Trip to Hawthorne Works, Western Electric Company.

Arrangements have been made to visit the Hawthorne Works of the Western Electric Company. The visitors will be conducted through welding installations which incorporate the use of automatic, semi-automatic and hand arc welding equipment and at least one spot welding installation. The trip will also include other representative manufacturing departments, including copper wire and rod manufacture, lead-covered cable manufacture and as many assembly and fabricating departments as time will permit. It is also planned to exhibit to visitors the principal features of sound picture equipment, which will be illustrated by means of a talking picture describing deep sea cable laying. Transportation will be by bus from the Congress Hotel.

Afternoon

2.00 p. m. Technical Session (Florentine Room adjoining Registration Foyer).

Presiding Officer—F. P. McKibben, vice-president, A. W. S.

"Application of Fusion Welding to Pressure Vessels," by J. H. Hodge, Babcock & Wilcox Company.

"Physical Properties of Electrically Welded Tubing," by J. S. Adelson, E. O. Sequist and H. L. Whittemore. The paper will be presented by Mr. Adelson.

"Magnetic Testing of Butt Welds," by T. R. Watts, Westinghouse Electric & Manufacturing Company.

Evening

6.30 p. m. Annual Banquet followed by Dancing—Gold Ball Room.

FRIDAY, SEPTEMBER 26

Morning

10.00 a. m. Technical Session (Florentine Room adjoining Registration Foyer).

Presiding Officer—E. Wanamaker, past chairman, Chicago Section.

RAILROAD SESSION

"Double Lengthening Railroad Rails," by L. C. Ryan, manager, Track Department, Oxweld Railroad Service Company.

"The Possibilities of the Further Development of Railroad Welding," by G. W. Lieber, Superintendent of Reclamation, Missouri, Kansas & Texas Railroad Company.

"Reclamation of Battered and Worn Ends of Railroad Track," by C. J. Bergunthal, Track Welding Supervisor, Southern Pacific Company.

"Elimination of Joint in Open Track," by J. H. Deppeler, Chief Engineer, Metal & Thermit Corporation.

WELDING EXPOSITION

Stevens Hotel

The Exposition will be open from 10.00 a. m. to 6.00 p. m. on Monday, Wednesday and Thursday.

On Tuesday and Friday the exhibit may be viewed between noon and 10.00 p. m.

Fall Meeting American Welding Society

A careful study of the program for the Fall Meeting of the Society during 1930 will reveal the fact that the Meetings and Papers Committee has been unusually successful in securing a large list of nationally known authors to present papers on timely welding subjects. There is much of interest to the practical man, as well as to the theoretical, and to the executive, as well as the engineer. Results of research work are prominently featured.

This issue, which contains a portion of the papers to be presented at the meeting, contains a wealth of information; additional facts will be brought out in the discussion. Every member connected with the Society owes it to himself, as well as to his firm, to be present and participate in this discussion.

Six or seven organizations will hold meetings in Chicago at the same time. A record attendance is expected at the exposition.

Mr. James H. Edwards Dies Suddenly

James H. Edwards, chairman of the Structural Steel Welding Committee of the American Bureau of Welding, died suddenly on Aug. 14 after a few days' illness. Mr. Edwards was chief engineer of the American Bridge Company, and was born in Oxford, Chenango County, New York, June 19, 1864. He graduated from Cornell in 1888. He entered the employ of the Berlin Bridge Company as structural draftsman. In 1897 he was appointed as chief engineer. The company pioneered in the steel frame type of industrial building and, through Mr. Edwards, developed it to high perfection.

In 1900, when the Berlin company

merged with the newly formed American Bridge Company, Mr. Edwards was appointed structural engineer; in 1901 he became assistant chief engineer, and in 1927 chief engineer. As assistant chief engineer he was in general charge of all building work and furthered a great deal of testing work, including the strength of beam connections, columns, riveted joints and angles. As chief engineer he continued his attention to the technical problem of design, but also gave considerable time to his new organizing responsibilities. He was in charge of the Bridge company's standardization activities and the development of new sections.

James H. Edwards

Mr. Edwards was gifted with remarkable clear-sightedness in technical matters and with an open mind. He took up the study of fusion welding and became convinced of its possibilities. He made tests and induced his company to establish a welding shop at its Trenton plant. New forms of structural design and detail suited to welding were developed under his supervision. Many of the important welded buildings came into existence largely due to his combined engineering and business vision. He took an active part in the work of the American Welding Society, became its vice-president and chairman of the Structural Steel Welding Committee, and organized for this committee an elaborate series of tests to secure fundamental design data on the application of welding in the structural field, which tests are now in progress. The Samuel Wylie Miller Medal of the Society was awarded him for conspicuous contribution to the advancement of the welding art.

In addition to his activities of the American Welding Society, he served as director of the American Society of Civil Engineers in 1913, was a member of numerous committees of this Society and other engineering organizations. For fifteen years he was Trustee of Cornell University.

Fundamental Research in Welding Field

Through the Fundamental Research Committee under the chairmanship of H. M. Hobart, a series of investigations have been started in a number of prominent universities on many phases of welding. This year an inspection trip and conference will be held during the early part of the week of Sept. 15, at which are expected representatives of some fifteen leading universities. A suggested list of problems has been compiled by the committee. For the information of the members of the Society these are reproduced below:

Suggested List of Fundamental Research Problems in Welding

1. The relation of ductility to other physical properties of welded joints, such as tensile strength, fatigue and resistance to impact.
2. Impact resistance of welded joints.
3. Effect of heat treatment on the strength and other properties of welds.
4. Effect of heat treatment on relief of locked-up stresses in welded specimens.
5. Effect of method of making arc and gas welds upon the ductility of the weld metal.
6. Relation between chemical composition (gas content) and mechanical properties of steel and the weldability.

7. Transference of metal in arc and gas welding with the aid of high speed motion picture cameras and other devices.
8. X-Ray study of crystal structure of welds.
9. Effect of peening on the quality of welds.
10. Effect of method of making welds upon alloy steels and non-ferrous metals.
11. Investigation of the fatigue and impact resistance of welded joints to determine allowable stresses to be used in design.
12. Effect of the heat of welding on the adjacent metal with various alloy sheet materials.
13. Fundamental laws governing magnetic disturbances and how may these troubles be overcome satisfactorily.
14. Comparative properties of welds made with covered and bare wire.
15. Calorimetric study of carbon and metal arcs.
16. Comparative merits of various types of joints on minimizing welding strains.
17. The effect of coating such as paint and galvanizing on weldability.
18. Tests on various types of connections of beams welded to columns.
19. Study of speed of welding and effect of amount of current.
20. Advantages and disadvantages of deep penetration.
21. Magnetic characteristics of various types of welded joints (for use in design of electrical machinery).
22. Non-destructive tests for welds.
23. Proper welding procedure to obtain satisfactory welds in hydrogen atmosphere.
24. The value of the Kinzel and Tuckerman Bend Test in determining ductility of welds.
25. The comparative effects of flame cut on steels of varying compositions.
26. Study of effect of size and shape of fillet welds on strength.
27. Temperatures and technique for strain annealing of various types of welds.
28. Temperature of oxyhydrogen-carbon monoxide flame with various ratios between hydrogen and carbon monoxide.
29. Temperatures of the craters of the d.c. and a.c. iron arcs in air and other gases.
30. The relationship between the nitride needles and physical properties of the weld.
31. The technique of the carburizing and nitriding of the welded metal.
32. Study of metal transfer by noting relative amounts of metal transferred in various positions of welding.
33. Comparative behavior of an arc with a pure iron electrode in argon and nitrogen and air with an arc formed by an electrode containing oxides or slag.
34. The effect of electrodes containing nickel and cobalt on the behavior of the arc.
35. Volt-ampere characteristics of an iron arc as a function of arc length.

Chairman Structural Steel Welding Committee

At a recent meeting of the Executive Committee of the American Bureau of Welding, Leon S. Moisseiff, consulting engineer in New York City, was selected to serve as chairman of the Structural Steel Welding Committee, a position made vacant by the recent death of J. H. Edwards. Mr. Moisseiff is well known throughout the country on prominent engineering projects, such as the building of the Manhattan and Queensboro bridges over the East River, and the strengthening of the Williamsburg Bridge. He was engineer of design of the Philadelphia - Camden Bridge, consulting engineer on the Ambassador Bridge between Detroit and Windsor, and the Maumee River Bridge at Toledo, Ohio. He is advisory engineer to the Port of New York Authority on the Hudson River and Kill van Kull bridges, is on the board of consulting engineers of the Golden Gate Bridge, San Francisco, and is consulting engineer to Commissariat of Transportation, U.S.S.R. He is a consulting engineer to the Chicago World's Fair Exposition, 1933, and a member of the American Society of Civil Engineers and its Joint Committee on Concrete and Reinforced Concrete.

SECTION ACTIVITIES

Philadelphia

The first meeting of this season will be held on Sept. 15. Charles Kandel, general manager, Craftsweld Equip-

ment Corporation, will give a paper on the "Development of the Ellsberg S-51 Underwater Cutting Torch," which was written by Commander Edward Ellsberg. A motion picture covering the activities in the raising of the U.S.S. "S-51" will also be shown. Mr. Kandel will also talk on "Industrial Projects on Which the Ellsberg Underwater Cutting Torch Has Been Used," which will be illustrated with numerous photographs. An exhibition of diving rig and complete underwater cutting outfit, including a demonstration of dressing a diver for his work, will also take place.

San Francisco

The first fall meeting of this section was held on Aug. 29 at the Athens Athletic Club, Oakland, at 7.30 p.m. This meeting was in the nature of a business meeting and was held for the purpose of finding out what the members want and what they will do during the next year to promote a wider application of, and confidence in, the welding of metals.

Some of the Contributors of Papers to the Fall Meeting of the A. W. S.

J. S. Adelson, chief metallurgist, Steel and Tubes, Incorporated, is joint author of a paper on "Physical Properties of Electrically Welded Tubing." He received Bachelors and Masters Degree from Case School of Applied Science and has been connected with the Barrett Company as research chemist with the Chemical Warfare Service, with the Elyria Iron and Steel Company, 1923, and with its successor, Steel and Tubes, Incorporated, since then. He is a member of the American Welding Society, American Society for Steel Treating and American Society for Testing Materials.

W. M. Dunlap, author of paper on "Arc Welding of Aluminum," was born in South Carolina. He received his bachelor's degree in chemistry from Clemson A. and M. College, after having seen two years' active service with the American Forces in France during the World War. He took up post graduate work and taught chemistry and metallography at Iowa State College. Since 1922 he has been associated with the Aluminum Company of America, first as chemist and then as metallurgist. During the past few years Mr. Dunlap has been closely associated with the research work in connection with the welding of aluminum and its alloys, developed spot welding of this material and other resistance methods and has recently developed a satisfactory flux for arc welding of aluminum and its alloys. He has written numerous articles on the subject of welding of aluminum, and is a member of the American Welding Society, American Chemical Society and American Society for Steel Treating.

C. H. Jennings, author of paper on "Fatigue and Impact Tests for Welds," was graduated from the Mechanical Engineering Department of Iowa State College. He has been connected with the Mechanics Division of the Westinghouse Electric and Manufacturing Company since 1928, where he has devoted his time to the fundamental investigation of the physical properties of arc welds.

Robert E. Kinkead, author of the paper on "Cost of Using Welding," was graduated from Ohio State College in 1913. He was engineer officer in the U. S. N. during the war and for a considerable period was chief engineer of the welder division of the Lincoln Electric Company. He entered consulting practice in 1927. He invented the spot annealing process and applied inductive stabilizer to arc welding machines. He has given considerable time for development of procedure control for pressure vessels. He is director and consulting engineer for Lukenweld, Inc., and is also consulting engineer of the Koppers Construction Company. He is author of book on "Weld Design and Production." He is a member of the A.S.M.E., A.W.S. and Cleveland Engineering Society.

Milton Male, joint author of the paper on "Stress Distribution in Side-Welded Joints," was graduated from M.I.T. in 1929 with a degree in Architectural Engineering. He has been engaged by the Structural Steel Welding Committee of the American Bureau of Welding, and at present, during a leave of absence, employed by the U. S. Steel Corporation.

Professor J. T. Norton, author of the paper on "Examination of Welds by

the X-Ray and Diffraction Method," was graduated from M.I.T. in 1918. From 1920-1926 he has been research associate, Department of Physics, M.I.T., from 1926-1929 assistant professor in the Department of Physics, and since 1930 associate professor, Department of Mining and Metallurgy. He has specialized in technical and industrial applications of X-rays and in problems of the physics of metals. He is a member of the American Physical Society, American Institute of Mining Engineers, the Institute of Metals, and American Society for Steel Treating.

Professor G. E. Thornton, author of paper on "Fatigue Investigations of Welded Joints," received his Bachelor and Master degrees from State College of Washington. From 1909-1912 he was connected with the Operations Division of the Washington Water Power Company and from 1917-1913 was technical expert with Emergency Fleet Corporation. Since 1918 he has been professor in mechanical engineering, State College of Washington. He is a member of several engineering societies.

T. R. Watts, author of paper on "Magnetic Testing of Butt Welds," was graduated from the University of Cincinnati in 1922. During the period 1922-1926 he was statistician of the Union Gas and Electric Company in their industrial sales department, and later (1926-1929) served as engineer in their electric meter and testing laboratories. Since 1929 he has been connected with the Westinghouse Electric & Mfg. Company and other research laboratories, where he has devoted his attention to the development of non-destructive tests for welds.

Walter H. Weiskopf, joint author of the paper on "Stress Distribution in Side-Welded Joints," was graduated from the Civil Engineering Department of Rensselaer Polytechnic Institute, where he was also elected to membership in Sigma Xi. Among the positions which he has held may be included architect for Thomas W. Lamb Company, engineer for the Department of Water Supply, Gas and Electricity in connection with design of High Bridge over the Harlem River, member of the firm of Weiskopf & Pickworth, engineer for the Carnegie Steel Company in the development of use of new shapes. At various times, and for several years, he has been connected with the American Bridge Company as draftsman, in charge of contracts of large structures such as Bank of America, 24 stories, and Equitable Trust, 38 stories, and designing and estimating engineer. Since 1929 he has been in private practice as consulting engineer.

H. L. Whittemore, vice-director of the American Bureau of Welding, is author of the paper on "Strength of Welded Joints in Tubular Members for Aircraft." Professor Whittemore was born in Milwaukee in 1876 and was graduated from the University of Wisconsin. In 1905 he assisted in the development of automatic telephone systems in Berlin, Germany, and later spent a year in systematizing work in the control division of the British Westinghouse Electric & Manufacturing Co., in Manchester. In 1906 he was in charge of inspection at the University of Illinois on testing material and hydraulics. Has also been connected with the Watertown Arsenal, Columbia University and the University of Oklahoma. Since 1917 he has been a member of the staff of the Bureau of Standards, where he serves as chief of the Engineering Mechanics Section. In 1928 he was awarded the Morehead Medal for his outstanding research work in the oxy-acetylene field. He is a member of the American Association of Engineers, American Society for Testing Materials, A.S.M.E. and A.W.S., and numerous technical committees.

James W. Owens, author of the paper "Tensile Tests for Welds," was born in 1886 and studied electrical engineering at the Polytechnic Institute of Brooklyn, N. Y. Prior to entering the welding field in 1918 he was engaged in railroad electrification and power station design and construction. He was welding aide for the Bureau of Construction and Repair of the Navy from 1918 to 1926 and director of welding for the Newport News Shipyard from 1926 to June of this year, when he became associated with the Welding Engineering & Research Corporation of New York as its engineering director. He is a past vice-president of the Society, at present a director and a member at large of the American Bureau of Welding. He is also author of "Fundamentals of Welding-Arc, Gas and Thermit," and in 1928 was awarded the first prize of $10,000 in the Lincoln Electric Company's international competition sponsored by the A.S.M.E.

The Examinations of Welds by the X-Ray Diffraction Method*

By John T. Norton†

THE use of X-ray diffraction methods in the study of problems of metallography is not new and during the past few years, they have yielded such important results that they are now among the regular tools of the metallurgist. X-rays afford information which is usually fundamental in nature and is of the greatest assistance in supplementing the better known metallographic procedures. The application of these methods to the problems of welding has been a part of the program undertaken by the Fundamental Research Committee of the American Bureau of Welding and it is proposed to describe some of the work which has been done in this direction. The present paper is to be regarded as a preliminary discussion of the method, and details of investigations now in progress will be presented shortly.

There are several different ways in which X-rays can be employed in the study of metals. The radiographic method is well known. The penetrating rays have been extensively employed to reveal the interior structure of castings and forgings and more recently have been used with great success for the non-destructive tests of finished welds. For several years, this work had been carried out at governmental and educational institutions as well as in industrial laboratories with the development of many special techniques and now has been accepted as a regular means of test. The results have been extensively described in the literature.

The diffraction or interference methods of using X-rays in the study of problems dealing with metals have been much less generally understood and made use of in metallographic research while their application to study of welding has been almost entirely neglected. These methods depend upon the fact that metals are crystalline and they yield two classes of information. The first is concerned with the atomic arrangement in metals and alloys and in nearly every case provides a definite picture of the manner in which the atoms are grouped to form the solid state. This arrangement has a great deal of importance in the study of the physics of metals. Information of this nature has a particular application to the study of alloys and often affords a complete explanation of an apparently complex system. The second class of information yielded by the diffraction method has to do with the granular state of the metal, that is, the size and orientation of the individual crystal grains. The physical properties of a metal depend to a large extent upon this granular structure and in particular the properties

*Paper to be presented at Fall Meeting of the A. W. S., Chicago, September, 1930. Report rendered to Fundamental Research Committee of American Bureau of Welding.

†Associate Prof., Dept. of Metallurgy. Mass. Institute of Technology.

which are important in welding, namely, strength, resistance to deformation, ductility and so forth. Obviously, then, a method which will shed some light upon this situation is of greatest importance.

There are numerous experimental methods of obtaining X-ray diffraction information, all based on practically similar general principles. A theoretical discussion of the problem of X-ray diffraction would be out of place in this paper but a general explanation is necessary and is perhaps best given by the consideration of a particular case. Probably the most generally used scheme for the study of granular structure is the so-called "pin-hole" method. A narrow beam of X-rays defined by small holes in lead diaphragms passes through the thin sample of the metal to be studied and falls upon a photographic plate. After suitable exposure, the developed plate is found to contain not only a dark spot due to the direct beam but also certain rings or dark spots which are dependent upon the structure of the sample.

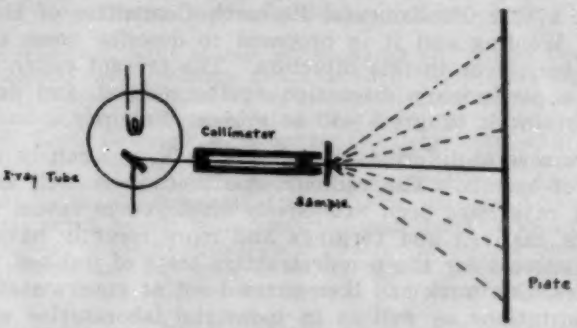

FIG. 1—SCHEMATIC ARRANGEMENT FOR THE "PIN-HOLE" METHOD

The source of the rays is an X-ray tube with an iron, copper or molybdenum target. It is operated from a high voltage source of such a value that the characteristic rays of the target material are given off. In the case of molybdenum this is about 30,000 volts. The beam of X-rays consists of a quite wide range of wavelengths, referred to as "white" radiation and a certain narrow range which is much more intense than the rest. This narrow band is the characteristic radiation of the target material and by suitable filters may be almost completely isolated from the white radiation, the result being a beam which is practically of one wavelength or "monochromatic." In the case of problems where precise quantitative information is sought such a monochromatic beam is necessary but in the more general cases of the study of granular structure, the unfiltered rays containing some white radiation are advantageous.

A collimating system is employed to define the X-ray beam to a small round pencil. It is usually made of two or more lead disks with tiny holes in the center of each, set a few inches apart in a small tube, through which the rays pass. The result is a nearly parallel beam about one half millimeter in diameter. The necessary conditions are a fine, sharply defined beam with small angular divergence and an

FIG. 2—MACROGRAPH OF WELD AND VIEW SHOWING LOCATION OF AREAS

FIG. 3—AREA NO. 7. COMPARISON OF X-RAY PICTURE AND MICROGRAPH

FIG. 4—AREA NO. 6. COMPARISON OF X-RAY PICTURE AND MICROGRAPH

PHOTOGRAPHS REDUCED TO ABOUT 2/3 ORIGINAL SIZE

absence of scattering of rays from the pin-holes which give a false impression on the plate.

The photographic plate employed usually has a special X-ray emulsion and this type is commercially obtainable. X-ray film are also employed but are not as satisfactory for fine work because of the difficulty of keeping them flat. The normal distance from sample to plate is 5 cm. but this may be altered to suit the particular circumstances. It is important that this distance be accurately known and that the plate be exactly at right angles to the X-ray beam.

The sample, through which the X-ray beam passes is placed close to the end of the collimator which is nearer the plate. Often the squared end of the collimator to which the sample is attached is sufficient mounting but for precise work, a goniometer head is employed which permits an accurate orientation of the sample. The sample thickness is dependent upon the material as well as the wavelength of the X-rays used and the optimum thickness for each case can be calculated. Using rays from a molybdenum target, the thicknesses which have been successfully employed are 0.030 in. for aluminum and its alloys and 0.002 in. for iron and steel. Care in the preparation of the specimen is of the utmost importance. The usual procedure is to make a transverse section of the weld and give it a rough polish so that it may be etched for macroscopic examination. Such examination shows the various layers in the metal, the extent of the actual weld and usually the heat zones which indicate the limits of recrystallization. If photomicrographs are desired for comparison with the X-ray pictures, the section is cut into pieces of suitable size for polishing and the areas to be examined are prepared in the regular manner for microscopic study. While still in the camera, it is often advantageous to outline the area under observation with a small circle drawn on the polished surface, so that the X-ray picture may be of precisely the same region. The specimens are then further machined so that tiny pieces of the correct thickness and each having one of the marked circles in its center are obtained. This final preparation requires the greatest care to prevent any distortion or bending. It is then filed down to within two or three thousandths of the final thickness and the finishing done by etching with some suitable reagent to remove the traces of cold work due to the filing. X-ray pictures of this type are very sensitive in showing small amounts of distortion and it is very important to be quite sure that the observed effects are really in the original material rather than resulting from the preparation of the sample.

The pattern which appears on the developed film depends upon the state of the material which is illuminated by the X-ray beam. This will be a small cylinder of metal whose diameter is that of the beam and whose length is the sample's thickness. Suppose this volume to be a single crystal grain as is possible in a coarse grained metal. The atoms of this crystal are arranged in a regular repeating fashion and according to a plan which is alike in all grains of the same substance. Each atom in this array is excited when X-rays fall upon it and becomes a secondary source, radiating in all directions. Since all of these secondary sources are spaced at definite distances and the distances are

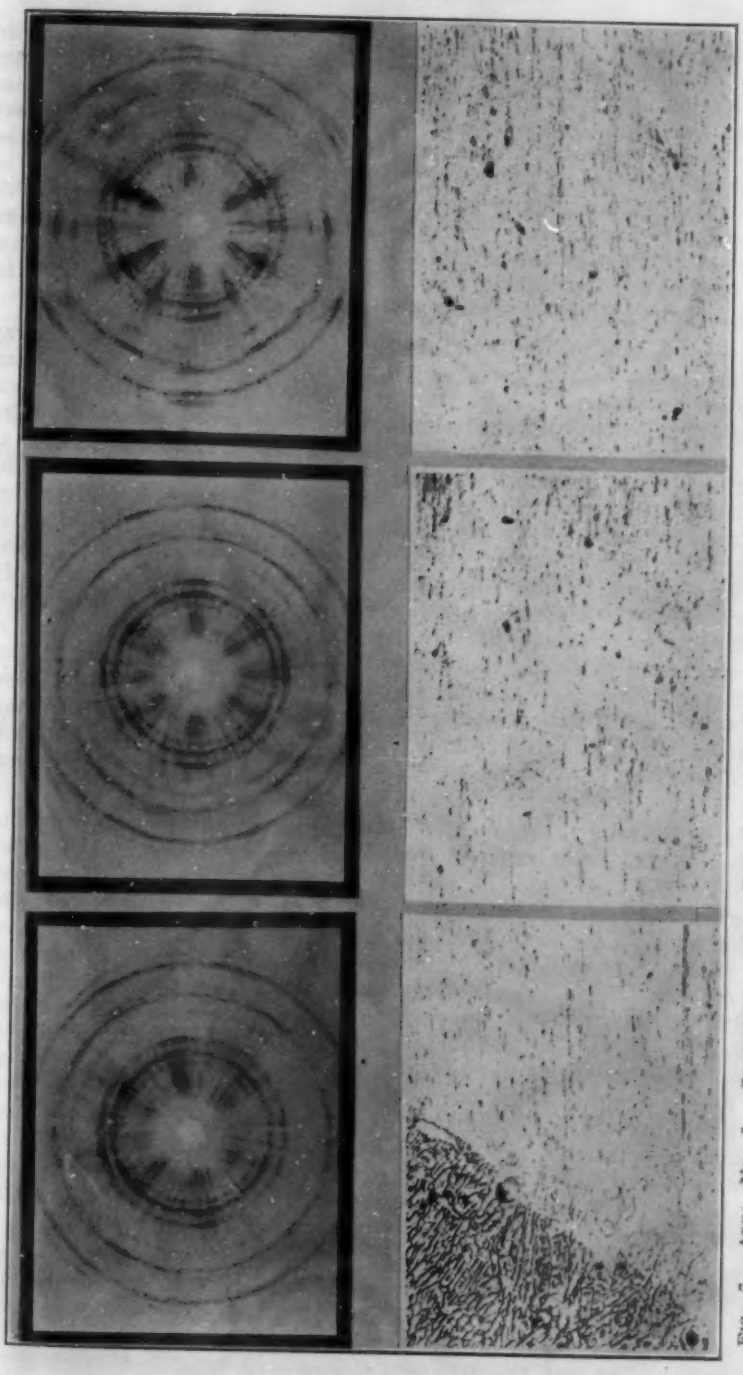

FIG. 7.—AREA NO. 3. COMPARISON OF X-RAY PICTURE AND MICROGRAPH

FIG. 6.—AREA NO. 4. COMPARISON OF X-RAY PICTURE AND MICROGRAPH

FIG. 5.—AREA NO. 5. COMPARISON OF X-RAY PICTURE AND MICROGRAPH

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of the same order of magnitude as the wavelength of the X-rays, interference takes place in such a way that in certain direction the beam is strengthened and in others it is destroyed. The result is a series of beams emerging from the sample at various angles from the direct beam. These interference maxima are surprisingly sharp due to the tremendous number of atoms in the small volume concerned and the very great regularity of their spacing. They appear on the photographic plate as small dark spots. The actual positions of the spots depend upon the orientation of the crystal grain with respect to the direct beam and if one of the crystallographic axes of the grain is parallel to the direct beam, the pattern assumes a definite geometrical configuration.

If the grain size of the metal in the sample is such that the X-ray beam illuminates two or three crystal grains at once, the resulting pattern shows an increase in the number of spots for it is really several patterns representing different orientations superposed. As the grains become smaller and more numerous the spots also become greater in number until they are fairly regularly distributed over the whole plate. With still smaller grain size the spots begin to group themselves into concentric rings and finally when the structure is that to be found in strongly cold worked metals, the rings are smooth and sharp with no traces of spots. These rings are the diffraction maxima due to the interference of the characteristic wavelengths in the X-ray beam with certain definite distances in the crystal. As the grains become so numerous it may be considered that they have every possible orientation and hence the rings are continuous and concentric with the direct beam. This change in diffraction pattern with grain size can be very plainly seen in the X-ray pictures from a series of transverse sections of cold drawn aluminum wire which have been annealed at different temperatures.

In cold working processes which are of a directional nature, a special condition of the granular structure appears which is generally called preferred orientation. As the metal is reduced in size, the deformation of the grains is accompanied by a rotation so that eventually the crystallographic axes of the grains become essentially parallel. This situation can be studied in a satisfactory manner by means of diffraction pictures. In the case of a fine grained metal where the grains are oriented in a completely random fashion, the resulting pattern is made up of a series of concentric rings. If the material is fine grained but only one or perhaps two orientations are present, the pattern consists of only segments of the rings. These segments may be so short as to be mere spots, depending upon the completeness of the parallel orientation. From theoretical considerations, one may determine the actual orientation in the sample from the appearance of the diffraction pattern and this work is of the utmost importance in dealing with problems of plastic deformation.

An operation such as welding which introduces intense local heating in the metal almost invariably sets up internal stresses in the interior of the sample due to uneven expansion and these stresses are relieved by an actual deformation of the metal. The individual crystal grains are slightly broken and the different elements of what was originally a

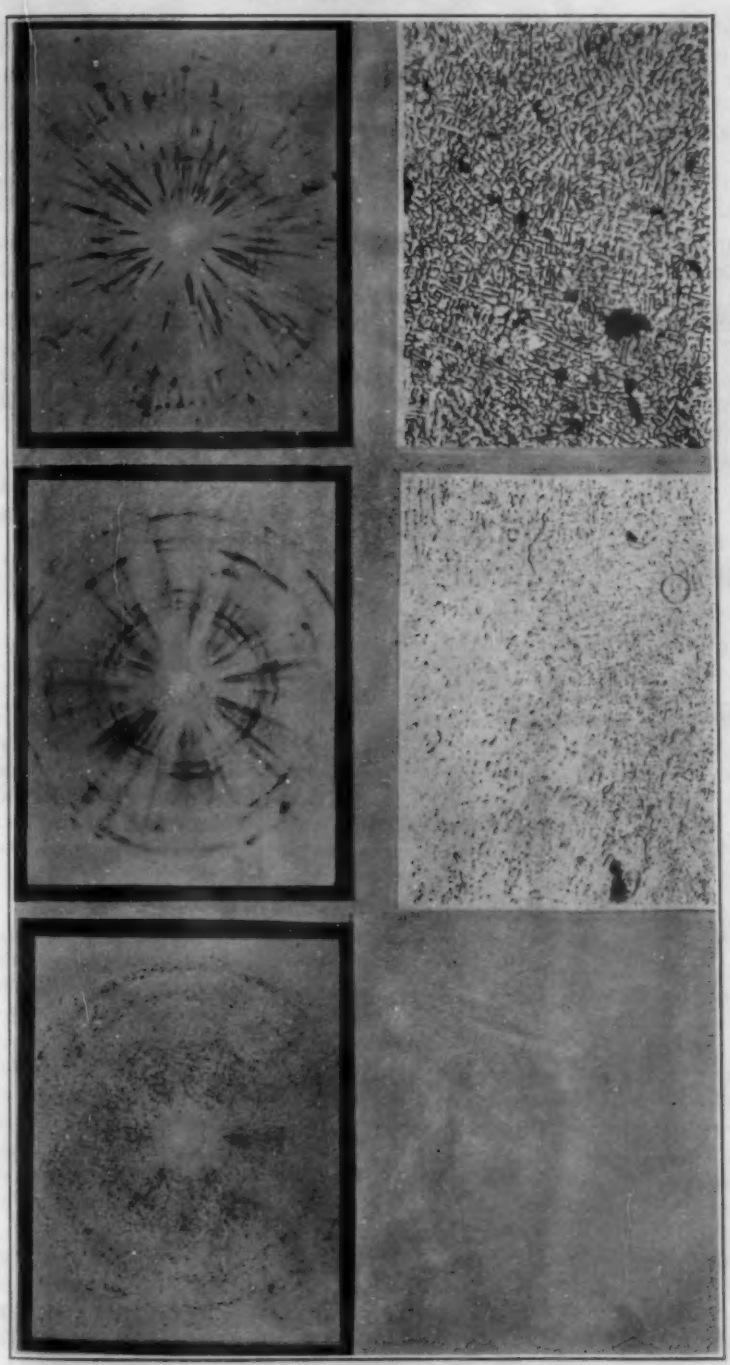

FIG. 8.—AREA NO. 1. COMPARISON OF X-RAY PICTURE AND MICROGRAPH

FIG. 9.—AREA NO. 2. COMPARISON OF X-RAY PICTURE AND MICROGRAPH

FIG. 10.—SMALL SAMPLE WITH SAME HEAT TREATMENT AS AREA NO. 3. NOTE ABSENCE OF ASTERISM

PHOTOGRAPHS REDUCED TO ABOUT 2/3 ORIGINAL SIZE

single grain, are slightly rotated with respect to one another. The diffraction maxima which result from such a grain are not sharp spots but are in the form of radial streaks upon which the spots are superposed. These streaks are really small spectra of the X-ray beam such as would be produced by an oscillating crystal and show all of the features of such a spectrum. If a filter is used to render the beam essentially monochromatic, the streaked appearance or "asterism" of the pattern practically disappears.

The appearance of asterism in X-ray diffraction pattern is of the greatest importance in showing the presence of internal strains in metal samples such as castings and welds. One can determine in what portions these strains exist and to what extent they have been eliminated by recrystallization. It is not possible to make a quantitative estimate of the amount of distortion in a particular sample but comparative results are of the greatest value, particularly since there is no other way in which the information can be obtained.

To illustrate the method which has been described above, the case of a weld with some very interesting features will be considered in some detail. The weld was made by the metallic arc process in aluminum sheet. The specifications are:

Material—2 S O Commercially Pure Aluminum—¼ in. plate.

Method—Metallic arc.

Filling Rod—Aluminum with 5 per cent silicon—3/16 in. dia.

Flux—No. 25—coating on filling rod.

Current—150 amp.

The weld was made from one side of the sheet only without beveling the edges and was in two layers. Two 12 in. x 6 in. plates were welded together to make one 12 in. x 12 in. plate. The aluminum was cold rolled sheet. Fig. 2 shows the macro structure of the weld as well as the location of the X-ray pictures. In each case the X-ray picture is accompanied by a micrograph of the same area, taken at a magnification of 75X.

Fig. 3 shows the structure at area No. 7 and is exactly like that of the original plate. The preferred orientation due to rolling is very complete as is shown by the short length of the circular segments. No change in the granular structure of the plate has been been produced by the heat of the weld, at this distance (1¼ in.). Fig. 4 which represents area No. 6 and is ¾ in. from the center of the joint shows exactly the same fine grained structure with parallel orientation. Fig. 5, representing area No. 5 which is ½ in from the center of the joint is very different. Here, the temperature has risen high enough to cause the beginnings of recrystallization and the smooth rings of Fig. 4 are now seen to be made up of many small spots. Most of these are sharp and do not show asterism, indicating that there has been little deformation of the plate in this region. There is also distinct evidence of the persistence of the preferred orientation due to rolling even after recrystallization has definitely commenced. Fig. 6 of area No. 4 shows more complete recrystallization and this would be expected since it is only ¼ in. from the center of the weld and undoubtedly reached a quite high tempera-

ture. Although the traces of the parallel orientation of the original state have almost disappeared, there is much increased evidence of asterism or radial streaks. These indicate that the uneven expansion due to differences in temperature have given the metal a permanent deformation. The same situation is to be observed in Fig. 7 except that the preferred orientation has practically disappeared and the strain or distortion in this region is somewhat increased.

Fig. 8 shows the condition in the weld metal itself at area No. 1. This is a typical cast structure of fairly coarse grain with the very pronounced strain which accompanies the rapid solidification of molten metal. The metal has not cooled fast enough to yield a quenched type of structure because the plate was well heated during the deposition of the first layer but the grain size, which is borne out by the micrograph, indicates that cooling was fairly rapid.

Fig. 9 is in the lower layer of weld metal which was deposited first. Here we have cast metal rapidly cooled and then reheated while the second layer was applied, at the same time being subjected to severe distortion due to the warping of the plates. The result is metal of somewhat finer grain than in area No. 1 but with very pronounced asterism. The photomicrograph shows also that the grain size in area No. 2 is smaller than in No. 1 but shows nothing of the condition of strain.

That the asterism in diffraction patterns such as Fig. 7 is really due to strains introduced by uneven expansion in the welded plates, can easily be shown. Fig. 10 is the diffraction pattern of a small sample of the same metal as the welded plate heated to the same temperature for the same time as area No. 3. Since the temperature of this small sample was practically uniform, it was not distorted on heating and cooling and it shows no trace of asterism. It does show, however, slight traces of the rolled structure of the original plate which have persisted even after complete recrystallization.

The application of the X-ray diffraction methods to the study of a welded joint in aluminum plate has been described as an illustration of the usefulness of the method in this type of work. The information which results is of a fundamental nature, much of which cannot be obtained in any other way and there seems to be a real need for research along these lines in the very important field of welding.

Cost of Using Welding*

ROBT. E. KINKEAD†

MANUFACTURERS are giving serious consideration, at the present time, to the matter of welding costs. The reasons for the interest in this subject are not difficult to find. Use of welding is spreading rapidly; perhaps more rapidly than at any time in the past 15 pears. Welding holds out a promise of important cost reductions. The matter

*Paper to be presented at Fall Meeting of the A. W. S., September, 1930.
†Consulting Engineer.

of welding costs would be comparatively simple if we had to deal with only one process. As a matter of fact, there are ten well defined welding processes which are different from each other in the matter of use in production and which produce widely different results in the physical behavior of the welded product itself. The situation is still further complicated by claims of vendors of equipment and supplies. Under the circumstances it appears opportune to d scuss at this time the foundations upon which cost estimates and cost predictions are based. We may, perhaps, examine a concrete case of a more or less typical nature with the thought in mind of getting sufficient information to state the fundamental problems in connection with cost prediction.

A plate fabricator sold a pressure vessel for $6,000. His cost department reported that the cost of the vessel loaded on a car in his plant was $4,800. What the cost department meant was that the cost of labor, material and overhead on the vessel was $4,800, according to their estimate. The plate fabricator paid a selling cost of 10 per cent or $600 to get the order for the vessel. This brought the cost up to $5,400. The fabricator's accountant showed a profit of 10 per cent or $600 on the transaction. This transaction is typical of a large number of similar cases and we may now pursue a serious inquiry into the situation to discover, if possible, what is the matter with our present conception of cost prediction.

From personal knowledge of the subsequent history of this transaction, the following facts may be stated. In three months the vessel referred to failed in service and the plate fabricator spent $800 putting it into operating condition. Six months later the vessel failed again and the plate fabricator replaced it on guarantee account. In the period covered by the last two calendar years, the plate fabricator has not been able to get additional business from that particular customer who, incidentally, is a large buyer of pressure vessels.

With the subsequent history of this transaction in mind, we may inquire what the cost of the vessel really was at the outset. We would certainly conclude that the cost of the vessel was unknown and for all practical purposes unknowable. The reason the cost was unknowable was that we have no way of estimating what dollar value should be assigned to the loss of good will which resulted from failure of the vessel. We might make a fair estimate of this loss in the case of the particular customer involved but we can make no estimate of the loss involved due to the fact that this dissatisfied customer was used by the plate fabricator's competitors to prevent him from getting business from other sources.

We may consider the matter from the point of view of the buyer. When he bought the vessel, he believed that his cost was $6,000, but after two failures with the accompanying loss of production, etc., his cost on the vessel was probably far in excess of $6,000.

In the case under discussion, therefore, we have now arrived at the point at which we do not know for certain what the vessel cost the plate fabricator or what it cost the buyer. We may perhaps reasonably conclude that the figure the cost accountant gave the plate fabricator as

the cost of the vessel was not really the cost at all. As a matter of fact, the cost accountant was dealing with a cost indicator which, in this particular case, was absurdly low as compared with the real cost. We have also arrived at the point at which we are certain that the real cost to the buyer was not $6,000; so that when the buyer's accountant indicated in the records the cost of the vessel as $6,000, he was grossly in error in the matter.

The case under discussion was chosen because it illustrates in a striking way the inadequacy of the cost indicator which is used in most transactions of this nature. We are reasonably certain that a general survey of buying and selling transactions would show that real costs vary widely, from the figures obtained by using the cost indicator, labor material and overhead. As a matter of fact, we are quite thoroughly convinced that many manufacturers are putting themselves out of business by placing too much confidence in the cost indicator which is obtained in this way. Many manufacturers are selling in a sharply competitive market with this fallacious cost indicator as reference point. We are personally aware of a number of competitive products in which the service life in one case is ten times the service life of the product in another case, yet the manufacturer of the equipment which has the longest service life is basing his selling price on labor material and overhead and comparing it with a similar figure which he estimates his competitor is able to reach. As a matter of fact the man with the long life equipment is giving his customer something that has an economic value of the order of 10 times the economic value of the product of his competitor. Under these conditions the manufacturer who has put economic value into his product probably has no one to blame but himself if he cannot earn profits.

Out of this situation has come a new conception in our minds of cost prediction. Possibly there is historical justification for a new conception of cost prediction. In the decade ending roughly in 1920, American manufacturing industry was what the advertising man calls production conscious. Orders were not hard to get. Productive capacity was below consumption requirements. Under these conditions it is obvious that the cost indicator, labor material and overhead, was significant. It seems entirely likely that in the decade beginning 1930 we will operate under different conditions. Orders are not plentiful. Production capacity is 50 per cent greater than consumption needs. The buyers attitude has undergone a considerable change. Office boy purchasing agents have gone out of style largely because they cost buyers too much money. Buyers under present conditions are fully aware of the fact that an incompetent business man will resort to practically any reduction in quality to keep his plant operating with low priced orders. More and more buyers are requiring information from vendors which will establish the *economic value* of the product. The initial cost is becoming less important than economic value. We do not infer that the millenium has been reached, but the tendency is toward consideration of economic value of a product rather than its initial price.

The question naturally arises as to how economic value can be established. Experience has shown that it is not as difficult as it appears

at the outset to establish the economic value of a product. Leaders in industry have been doing that very thing in recent years. The product is tested under the direction of scientifically trained observers under service conditions or a close approximation of service conditions. The physical laboratory is no longer a luxury in industry. It is rapidly becoming a necessity and its economic function is to establish the economic value of the product manufactured. "Life" tests are being run and the data published on many kinds of machinery and equipment. The purpose of such life tests is to establish economic value and to discourage the competitor who quotes a lower price on an inferior product.

In the welding field we are becoming convinced that the mere fact that a weld may be produced which is stronger than the parts joined is not significant. We are duly impressed when a manufacturer can be making a thousand welds which are *all* stronger than the parts joined because it shows that his methods have been refined to the point at which the quality of the product is not dependent on skill or good intent of the operator. We are becoming increasingly aware of the fact that resistance to tension loading is only one service requirement to be met in the case of welded joints. Resistance of corrosion, to fatigue, to high temperatures, and the other service requirements are quite as important, and in many cases more important, than resistance to tension loading. The service behavior of welded structures or products with reference to these conditions determines the economic value of the welded product. Professor Moore of the University of Illinois ran some life tests on pressure vessels, for instance, in which he showed that the life of a pressure vessel welded in a certain way was of the order of 400,000 cycles of service loading but the same vessel welded in another way had a life of the order of 5000 cycles. It seems to us that Professor Moore's work established the relative economic value of the product when welded by the two different methods. It is quite probable that the buyer would be willing to pay considerably more for a vessel which would stand 400,000 cycles than he would for one which would stand only 5000 cycles. What is true of pressure vessels, such as Professor Moore investigated, is also true of welded buildings, welded automobile parts and industrial equipment. Possibly the outstanding example of development and research work in this field is the case of the A. O. Smith Corporation which carries on an elaborate program of research and study to establish the economic value of its products. If we are correctly informed the initial price of these products is based upon economic value rather than the combined labor material and overhead costs.

The cost indicator we have been using certainly cannot be abandoned. It may be used as a yard stick for day to day or month to month performance of a production organization but under the conditions to which American industry is subjected in 1930, we need an additional cost indicator which is based upon the economic value of the product as obtained from life tests. This is particularly true in the case of welding where technical knowledge is not widely disseminated.

Stress Distribution in Side-Welded Joints*

By W. H. Weiskopf† and Milton Male††

(The notation used throughout this paper is given in Appendix A)

THIS paper presents three new features in connection with side-welded joints; that is, joints in which the welds are disposed parallel to the direction of stress. They are:

(1) A theory as to the manner in which welds deform under shearing loads and, resulting therefrom, a determination of the value of the Detrusion Ratio, D.
(2) A means of determining the effective areas of the bars composing such a joint (i. e., the percentage of the total areas that should be considered as transmitting load).
(3) A method of determining the length of welds, such that the maximum shear stress will not exceed the average design stress by more than any desired ratio.

The authors offer these, not with any idea that the problem is completely solved, but as practical suggestions that may be used with safety pending further investigation.

Two years ago a discussion by prominent engineers as to the behavior of fillet welds in transmitting shear from the cover plates of heavy girders led to a series of six tests at the Bureau of Standards in Washington. Simultaneously, but quite independently, the late Professor Peter Gillespie of the University of Toronto undertook to investigate a similar problem, the results of which confirmed the suspicion that shear distribution along a side-weld was not uniform.

The next practical step forward was an experimental study of the stress-strain characteristics of welded joints by Professor J. Hammond Smith at the University of Pittsburgh, the results of which, without analysis, were fully reported in the September, 1929 issue of the Journal of the American Welding Society.

To answer several unexplained questions arising from the 1929 tests, a new series was begun this year under Professor Smith's direction by Messrs. Haven, Logan and Hobe, seniors at the University, and reported in a thesis, "Strain Characteristics of Fillet Welds." A summary of the results of this thesis is here presented. Continued reference to both the 1929 and 1930 series will be made further on in discussing the theoretical analyses.

1930 *University of Pittsburgh Tests*

The test specimens this year were composed of wide bars united by long welds. The grip bars and the joint, or cover bars, were 10 and 8 in. wide, respectively, and the welds were 7 in. long. Measurements of strain

*Paper to be presented at Fall Meeting of the A. W. S., Chicago, September, 1930.
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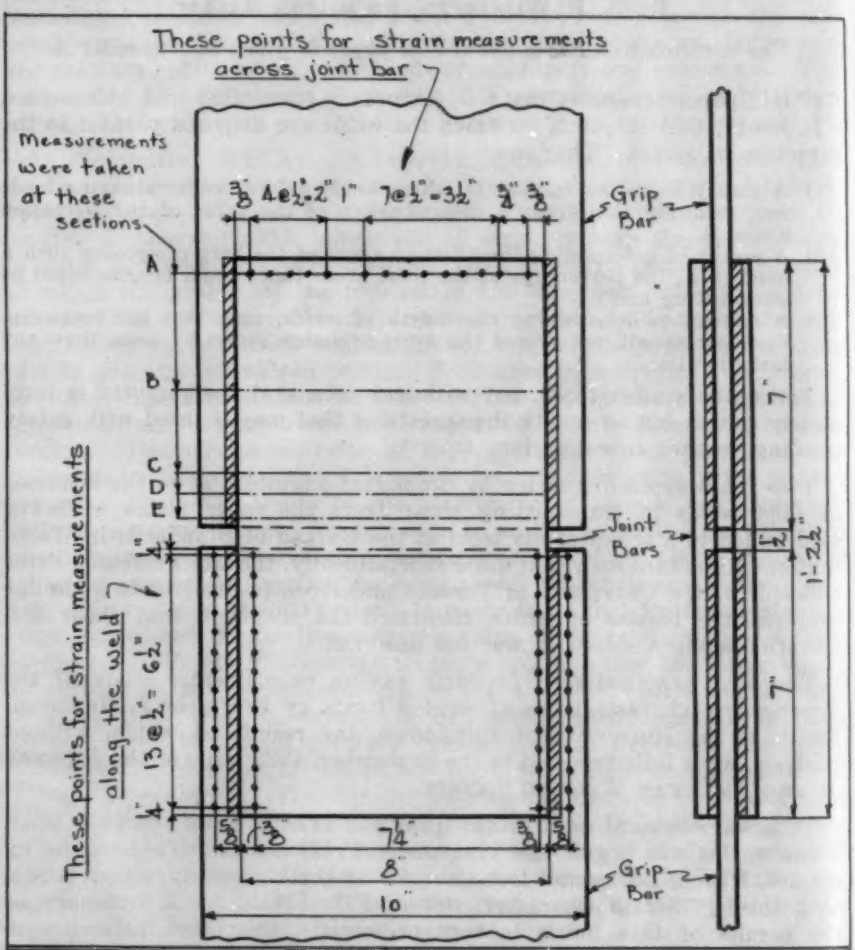
were taken, both along the weld and across the joint bars. Fig. 1 shows the dimensions of the joint elements and the location of the points and sections at which measurements were taken.

The instrument used to measure the strains had functioned most satisfactorily in the 1929 tests, in which the majority of specimens were



MARK	JOINTBARS	A_1	GRIP BAR	A_2	WELD
LA3	2-8×$\frac{9}{16}$"	9.0	10×$\frac{7}{8}$"	8.75	$\frac{3}{8}$"×7"
LC1	2-8×$\frac{1}{4}$"	4.0	10×$\frac{3}{8}$"	3.75	$\frac{1}{4}$"×7"
LB1	2-8×$\frac{3}{8}$"	6.0	10×$\frac{5}{8}$"	6.25	$\frac{1}{4}$"×7"

FIG. 1—1930 TEST SPECIMENS

composed of 3 in. grip and 2 in. joint bars of various thicknesses. Inasmuch as the specimens this year were much wider, the effect of eccentricity introduced by supporting the yoke on points quite distant from its center of gravity could not be neglected.

The instrument was modified therefore, by adding an adjustable counter-weight to balance the yoke on the outermost screws, another dial was added to make the readings more accurate, and the contact screws were made larger and sturdier. Fig. 2 gives an excellent view of the modified instrument mounted on a specimen ready for testing.

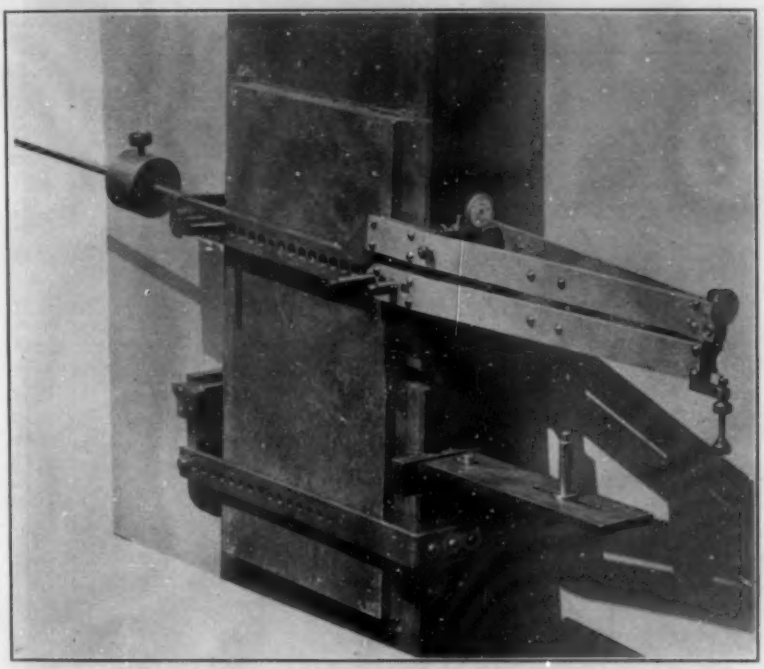


FIG. 2—VIEW OF INSTRUMENT MOUNTED ON SPECIMEN

The manner of testing was described in the 1929 paper and will not be repeated here. The larger bars and longer welds of the 1930 series permitted greater loads, and readings were taken at 24,000, 48,000 and 72,000 lb. loads. Not all specimens, however, were measured at the 72,000 lb. load.

Figs. 3, 4 and 5 show the results obtained by measuring the strains along the weld over a zone 1 in. wide. Strains in millionths of an inch are plotted as ordinates, and the distance in inches from the end of the joint bar as abscissae. The significance of taking measurements over a zone an inch wide will be discussed further on.

Figs. 6, 7 and 8 show the curves of strain measured across transverse sections of the joint bars. One set of measurements was taken at a section near the top of the joint bar, Section A of Fig. 1, one near the

middle of the weld, Section B, and three near the end of the weld, next to the center line of the joint, Sections C-D-E.

While curves were determined for all loadings, only the curves showing the deformation at the 48,000 lb. load are here plotted. The strains are very nearly proportional to the load, and the omission of other curves for the same section makes the chart easier to read and interpret.

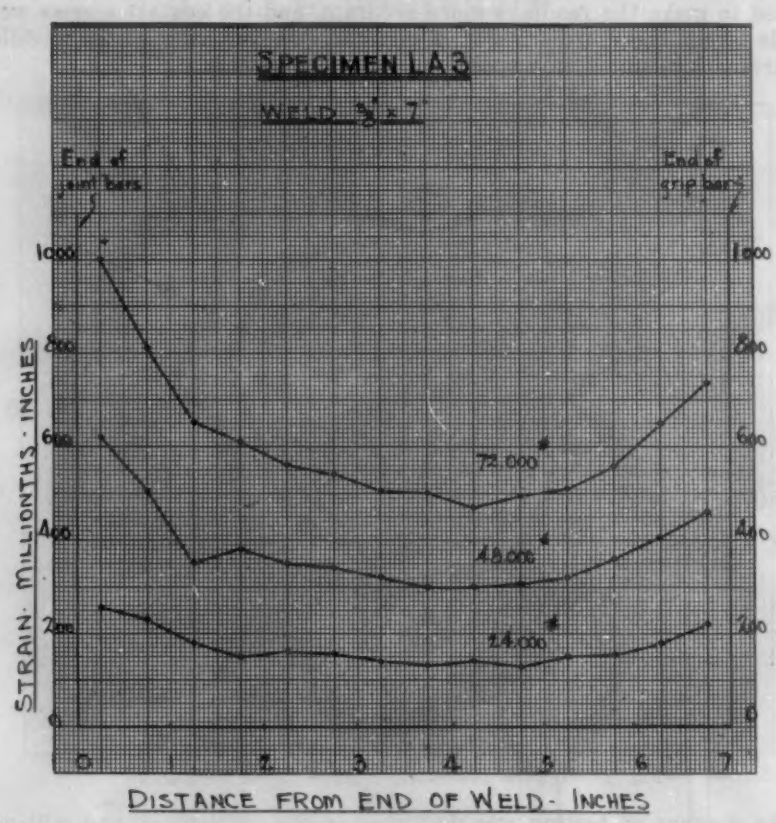


FIG. 3—STRAINS ACROSS WELD—SPEC. LA3

One change has been made in presenting these graphs. In the thesis, the origin, or reference-point was assumed to be a point on the grip bar, and the curve rose from this point to a maximum at or near the center line of the joint bars. Since the center line deforms least, and the edges of the bar most, the curves have been inverted and the origin placed at the center line, with the curve rising to a maximum at the point on the grip bar. It is apparent that the relative deformation of one point with respect to any other remains unchanged by thus presenting the curve.

The depression below the origin of the curves for specimens LA3 and LB1 (Figs. 6 and 8) taken at Section E nearest the center line of

the joint, appears to suggest either a slight eccentricity in the specimens, which might cause a reversal of strain where a bar first picked up load, or a compression due to Poisson's effect. The magnitude of these depressions is so small that they may be disregarded. They disappear further along the bar.

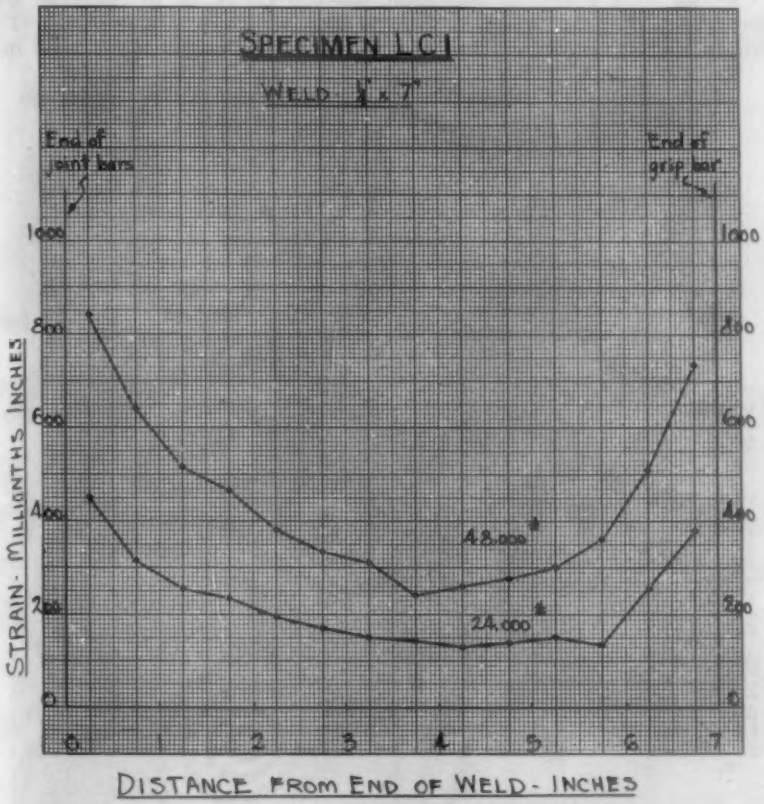


FIG. 4—STRAINS ACROSS WELD—SPEC. LC1

Theory of Weld Deformation

The tests made at the Bureau of Standards led to a mathematical analysis of the distribution of shear along the welds of a side-welded joint. Formulae were derived that quantitatively indicated, it is believed for the first time in history, that the shear is a maximum at the ends of the welds. A similar condition undoubtedly exists in joints made by any process, although it has commonly been disregarded.

The fundamental relation expressed in that analysis was the formula*

*From the manuscript, "Detrusion Tests of Longitudinal Fillet Welds," by Edwards, Whittemore, and Troelsch, to be submitted to the Bureau of Standards for publication in the B. S. Journal of Research.

$$q = \frac{v}{D}$$

where D, the Detrusion Ratio, is a measure of the stiffness of the weld and was to be determined experimentally. It was assumed to vary with the size of the fillet.

D is the unit shear on the weld itself divided by the corresponding deformation of the weld. Its value as used in the mathematical analysis is not immediately found from any of the tests that have yet been made.

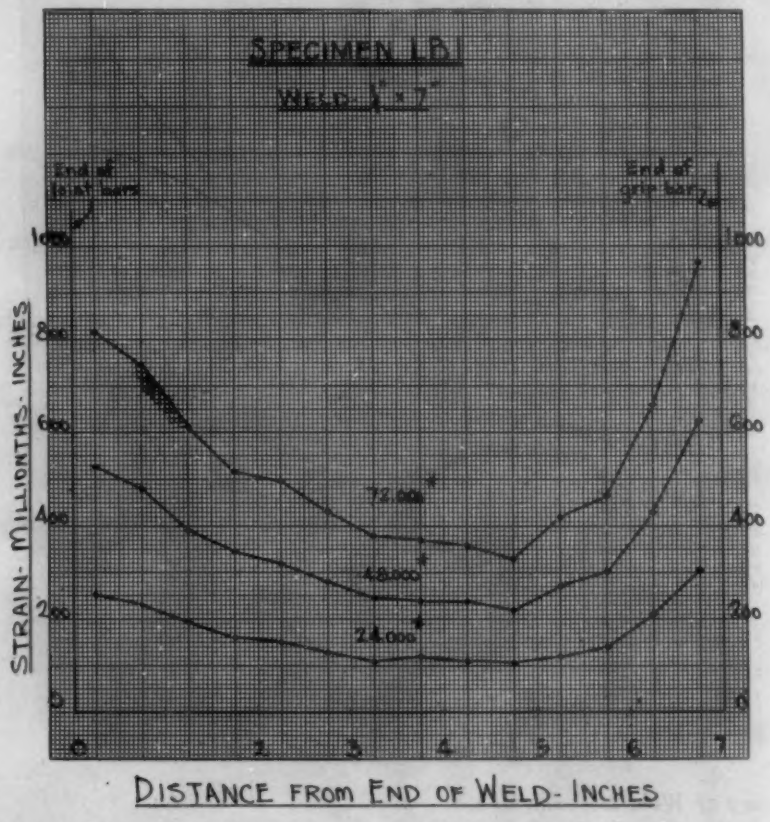


FIG. 5—STRAINS ACROSS WELD—SPEC. LB1

Tests have given only the deformation between points on both sides of, and some distance away from, the weld, and for a given shear this deformation will be greater than that of the weld itself. How much greater depends on assumptions, the present justification for whose use lies mainly in the fact that they give results conforming approximately to the tests.

We may assume that, along the throat of the fillet, from the root to the hypotenuse, one of three conditions applies:

(1) both shear and deformation vary non-uniformly, or

(2) the shear varies in such a manner that the deformation of all slices is a constant, or

(3) the deformation varies so that the shear on all slices is a constant.

The first assumption is discarded as being unworkable. The second results in a shear of infinite magnitude at the root, which can be avoided only by considering the root beveled to a depth which must be determined

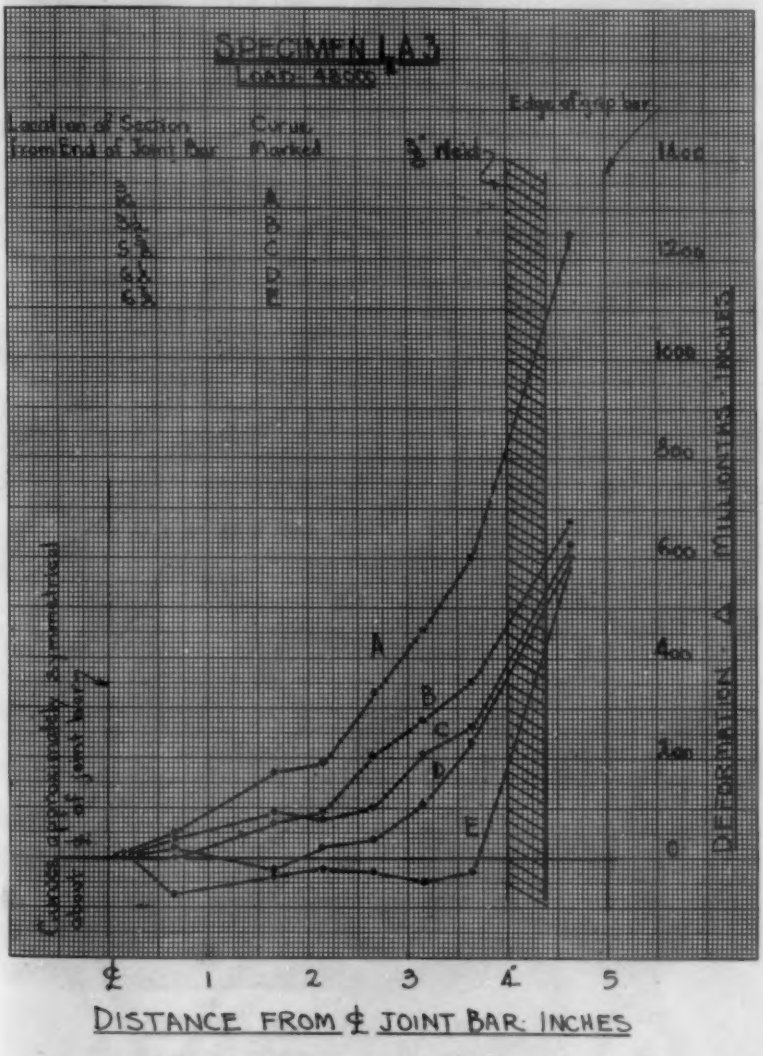


FIG. 6—DEFORMATIONS ACROSS BAR—SPEC. LA3

empirically. The third assumption gives zero deformation at the root and maximum deformation at the hypotenuse, which appears reasonable. This assumption means that each cross-sectional slice of the fillet is considered pivoted at the root, which therefore forms a convenient origin.

The authors are starting with this assumption in presenting a theory in which the value of D is determined theoretically.

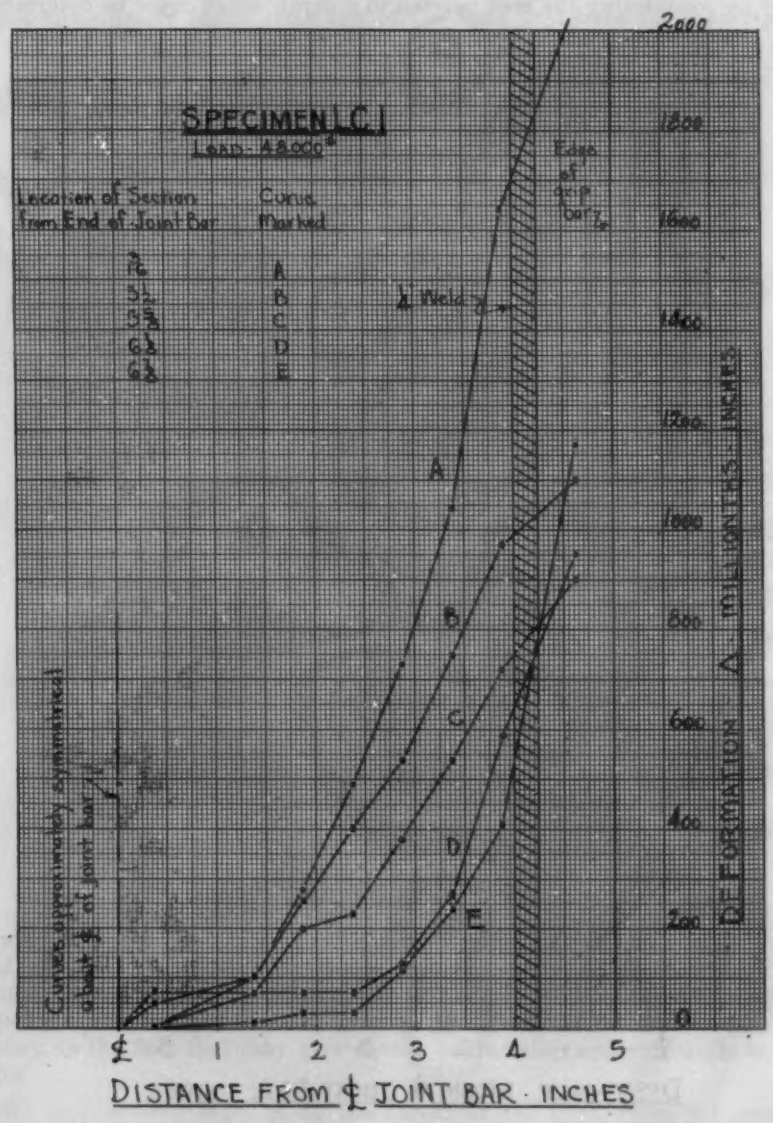


FIG. 7—DEFORMATIONS ACROSS BAR—SPEC. LC1

In Fig. 9 let V = total shear on any triangular fillet in a direction perpendicular to the paper.

Let V be uniformly distributed along the two legs of the fillet and hence across the throat, T.

Therefore the shear on any strip of unit width

$$v = \frac{V}{T}$$

Let q = the deformation of any strip distant X from O.

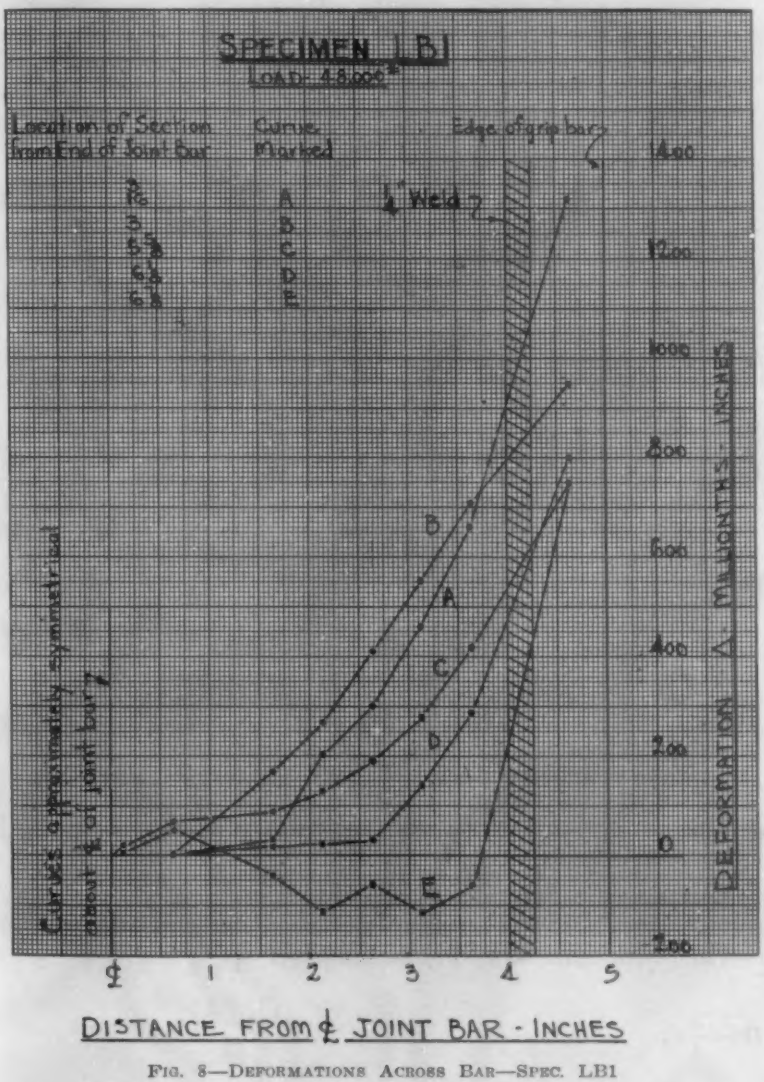


FIG. 8—DEFORMATIONS ACROSS BAR—SPEC. LB1

Then

$$q = X \frac{H}{T} \cdot \frac{V}{T} \cdot \frac{1}{G} = \frac{VHX}{T^2G}$$

Now let Q, the deformation of the entire fillet, be measured by the deformation of a strip passing through the center of gravity of the fillet, parallel to the hypotenuse H.

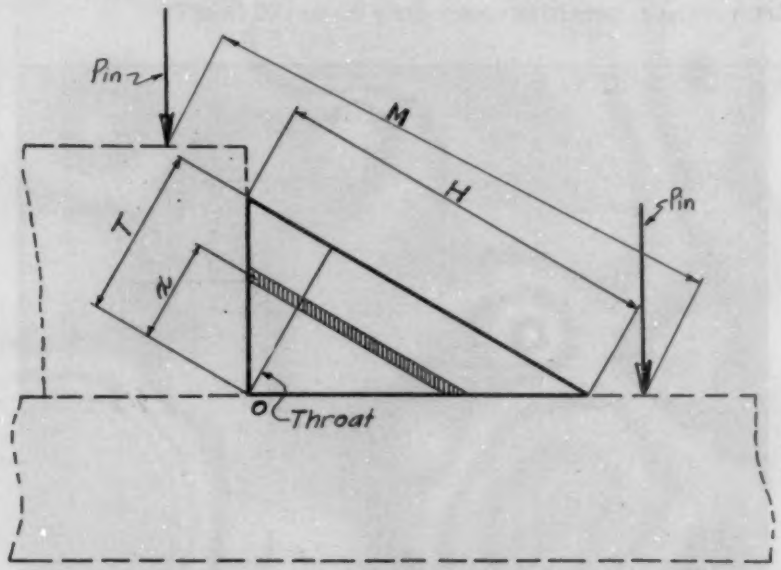


FIG. 9—SECTION THROUGH FILLET

Then

$$X = \frac{2}{3} T$$

and $$D = \frac{V}{Q} = \frac{V \cdot T^2G}{VH\frac{2}{3}T} = \frac{3}{2} G \frac{T}{H}$$

The expression $D = \frac{3}{2} G \frac{T}{H}$ applies to the general case of any triangular fillet. In common practice today, fillets are made with a right angle at the root and with equal legs. For such fillets $T = \frac{H}{2}$

and $D = \frac{3}{4} G$

The value of D, then, is taken as constant for a given weld material, and as independent of the size of the fillet.

In comparing the true value of D with the apparent detrusion ratio D_p, as measured between points straddling the weld, it was observed that D_p was approximately equal to D divided by twice the diagonal distance in inches between the points and this relation has been adopted in our theory. This means that the zone across which D is effective would be

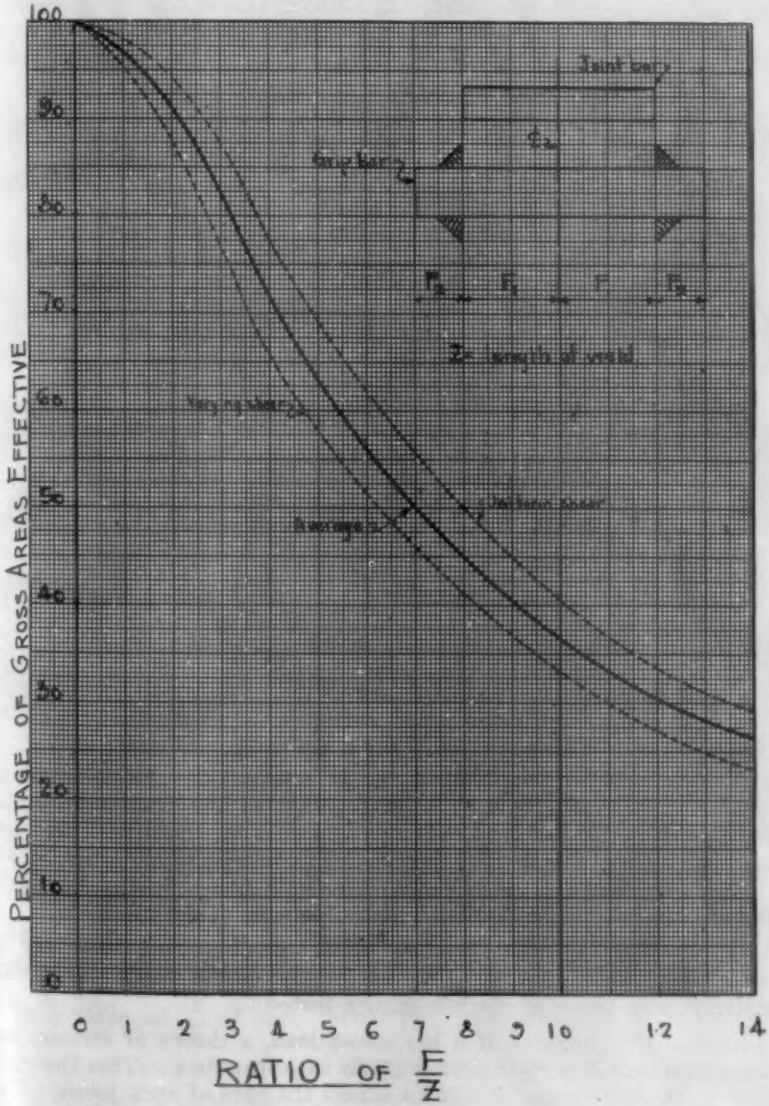


FIG. 10—EFFECTIVE AREA CURVE

one-half inch wide but what the physical significance of this zone is the authors are not able to explain at the present time. It has also been impossible to reconcile the theory presented here with one short weld specimen in the 1930 series of the University of Pittsburgh tests. This was a specimen whose bars were the same as those of specimen LA3, but attached by ⅜-in. weld only 2 in. long, located half way between the ends of the joint and grip bar. Since only one such specimen was tested, it is impossible to draw any definite conclusions from the results of the test.

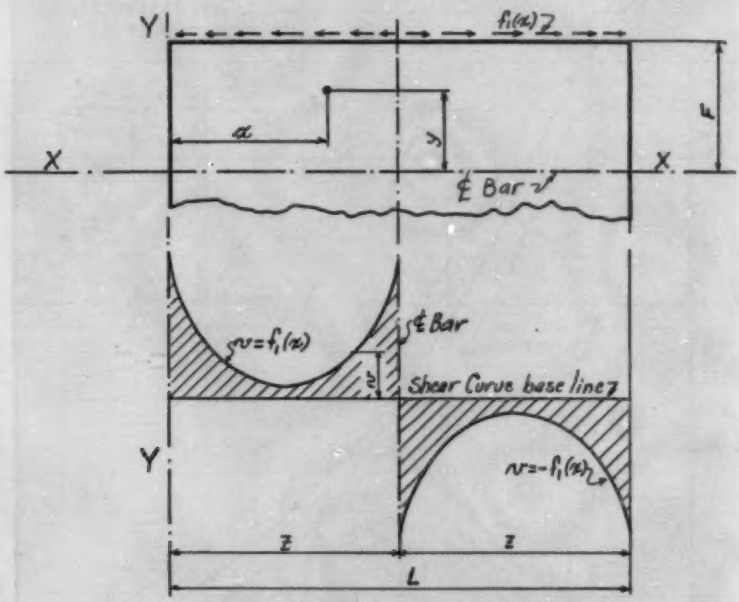


FIG. 11—FORCES AT LINE OF WELD

Effective Areas

In the analysis by Troelsch previously referred to, the equation for the shear curve was derived by assuming that at any transverse section through joint and grip bars, the stress carried by those bars was uniformly distributed over their respective total cross-sectional areas, A_1 and A_2. This assumption is one that is commonly made, with a negligible degree of error, in connection with many features of design.

In the case of the welded joints under consideration, however, the error becomes important, for this assumption gives results that vary excessively from those of every specimen tested.

To analyze the behavior of a bar under load, a theory of stresses and deformations was developed, and is given in Appendix C. This theory as checked by measurements of strains across the bars of such joints (Figs. 6, 7 and 8), shows that the stress is not distributed uniformly but that

the portions next to the weld are stressed to a much greater degree than those further away. To assume that the shear distribution along the weld is the same for both uniform and non-uniform stress in the bars would not be correct, and might lead to erroneous results.

The labor in computing the actual distribution of stress across the bars for any given case makes such a method unsuited to practical design.

It is desirable, therefore, to find what equivalent areas, if concentrated at the line of weld, would produce the same total deformation as actually results. Such equivalent areas will be called the percentage of gross areas effective, or briefly, their "effective areas."

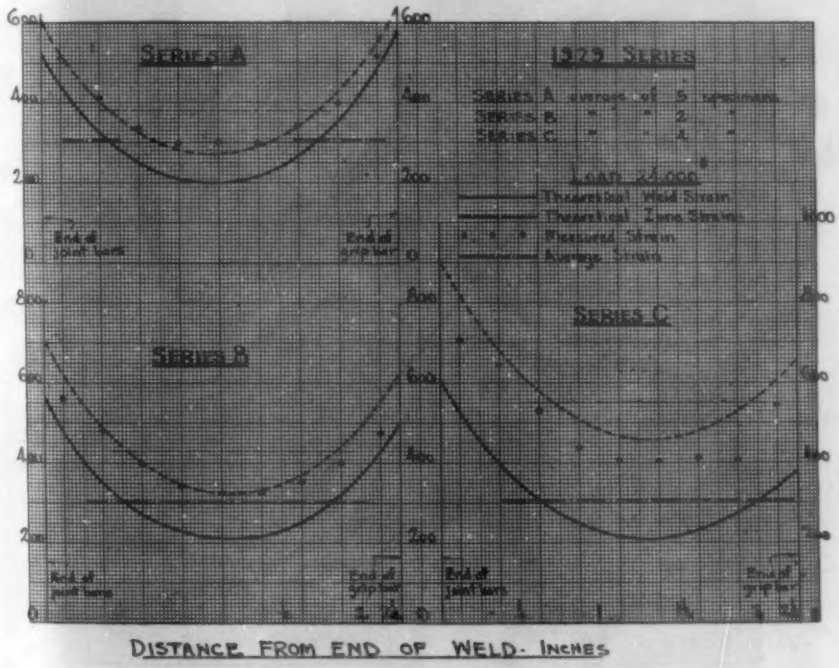


FIG. 12—THEORETICAL AND MEASURED STRAINS—1929 SERIES

Fig. 10 shows a curve giving the effective areas (percentage of gross areas) for various ratios of $\frac{F}{Z}$, in which Z is the length of the weld and F the distance from the weld to an axis of zero shear, which may be either a line of symmetry or a free edge.

At a ratio of $\frac{F}{Z}$ of zero (when the area is all concentrated at the weld) all of the gross area is effective; when the plate widens out to a ratio of $\frac{F}{Z} = 1$, only 37 per cent is effective. As the ratio increases

beyond 1 the curve varies hyperbolically in such a manner that although the percentage of effective area becomes smaller the absolute area remains constant for a given thickness. It is apparent, therefore, that increasing $\frac{F}{Z}$ beyond the limiting practical ratio of 1 will add nothing to the effective areas, a_1 or a_2.

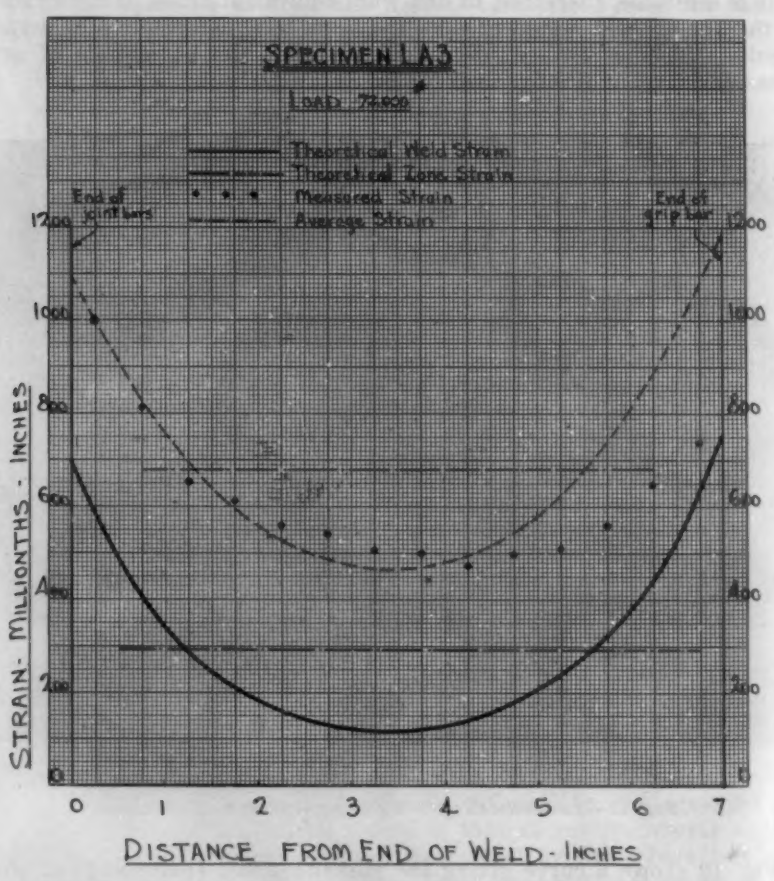


FIG. 13—THEORETICAL AND MEASURED STRAINS—SPEC. LA3

The curve was derived as follows:

In Fig. 11, a plate, symmetrical about the axis X-X, is acted upon by two shearing forces in opposite directions, $f_1(x)$ and $-f_1(x)$, varying so as to give curves rising steeply to maxima at the ends of the weld.

With the shear curve $f_1(x)$, the values of k_n (Equation H, Appendix C) were evaluated and these, in turn, used to compute the total deformation (Equation S) in the length Z of the weld.

Returning to the conception of effective areas, assume a piece of metal of area a, and length L, to be acted upon by the same shearing forces $f_1(x)$.

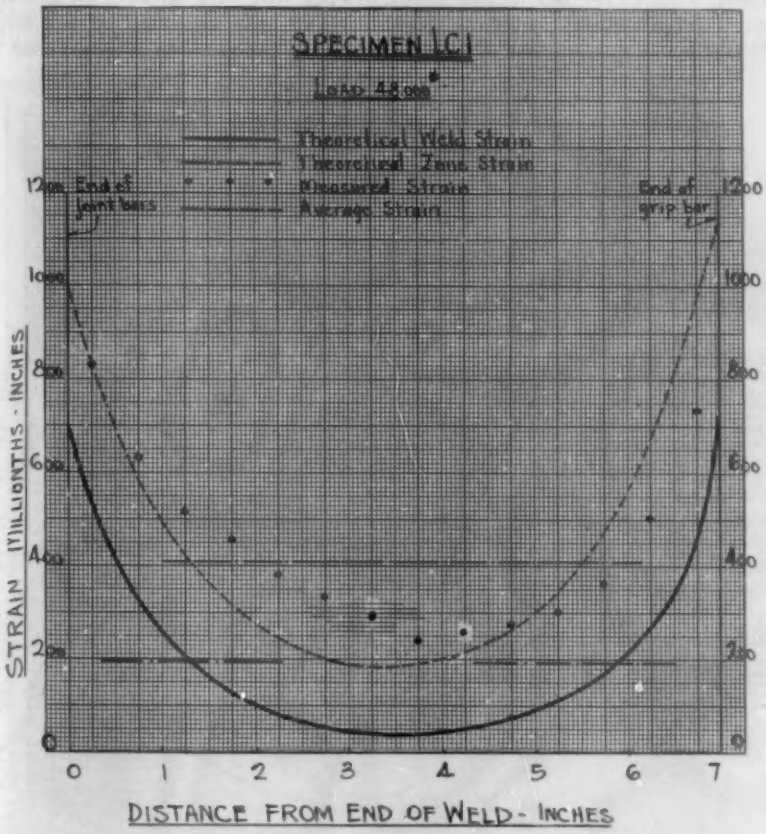


FIG. 14—THEORETICAL AND MEASURED STRAINS—SPEC. LC1

The intensity of stress at any point is

$$p = \int_0^x \frac{f_1(x)dx}{a}$$

and the deformation in the distance $\frac{L}{2}$ is

$$\Delta = \int_0^{\frac{L}{2}} \frac{p\,dx}{E}$$

By equating the deformations for both cases a simple equation results,

which for any value of $\frac{F}{Z}$ can be readily solved for the corresponding value of a.

This curve is plotted as the lower broken line of Fig. 10. In a similar manner an absolutely uniform shear f, (x) was assumed to act on the bar, and the upper broken line was plotted. Since all practical cases will

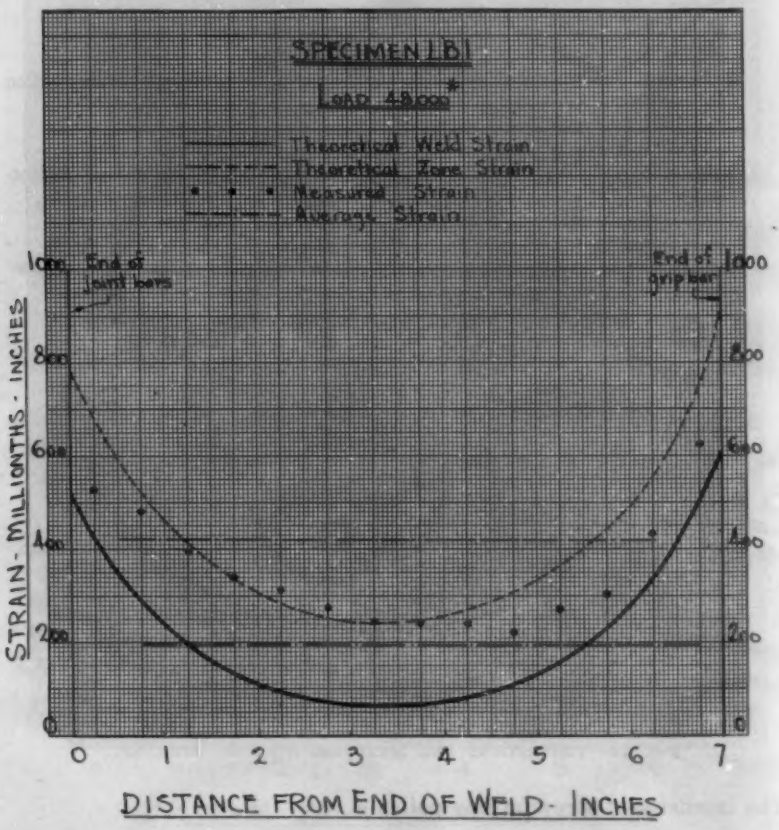


FIG. 15—THEORETICAL AND MEASURED STRAINS—SPEC. LB1

fall somewhere between these two limits, the intermediate heavy continuous line is submitted as one that will meet the average condition.

Comparison of Theoretical With Measured Curves

Let us now compare the theoretical shear curves with the measured curves. With the value of $D = \frac{3}{4} G = 8{,}700{,}000$, and effective areas as given by Fig. 10, shear curves were evaluated by the equation

$$v = \frac{Pr}{bN\,(r+1)}\left\{\frac{r\cosh\frac{z}{b}+1}{r\sinh\frac{z}{b}}\cdot\cosh\frac{x}{b}-\sinh\frac{x}{b}\right\} \quad \text{(Equation II Appendix B)}$$

for each of the specimens in the 1930 and 1929 tests with the exception of 1929 series D. This series embraced wider specimens and at the time

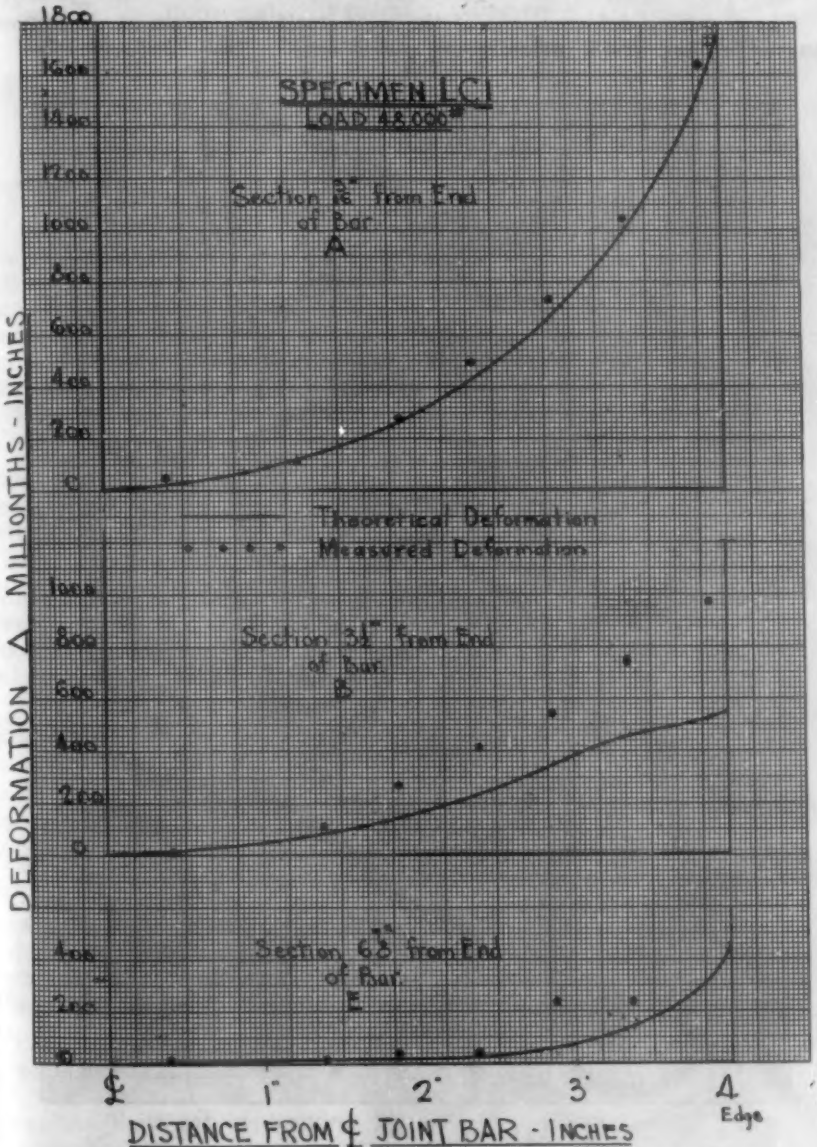


FIG. 16—THEORETICAL AND MEASURED DEFORMATIONS—SPEC. LC1

they were tested the instrument had not been corrected to measure wide specimens. The results of this series have, therefore, been disregarded.

With the shear curve determined, it was translated into a deformation curve by the simple relation

$$q = \frac{v}{D}$$

The resulting deformations of the weld itself are shown as continuous curves in Figs. 12-15, inclusive.

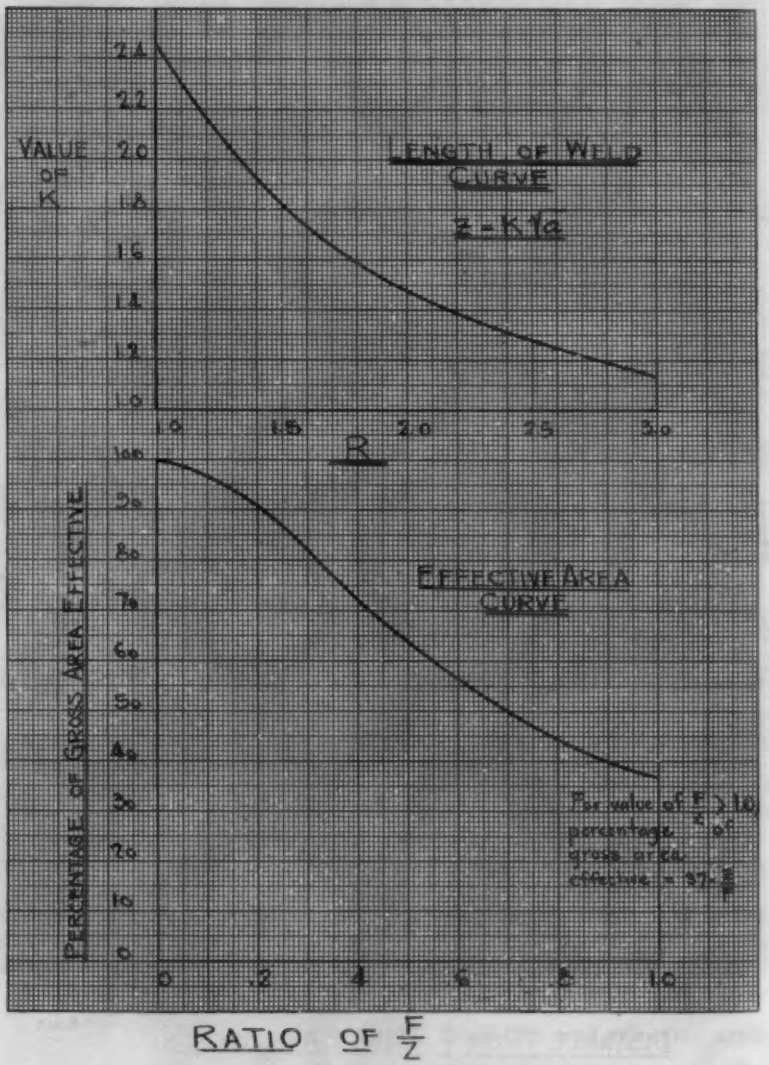


FIG. 17—CHART FOR DESIGNING

The measured deformations are plotted above as solid circles, and the theoretical zone deformations are shown as broken curves, determined from the relation of D_p to D, previously given.

The following table gives the data from which D_p was calculated:

Type or Series	Distance Between Pin Points (Inches) Horizontal	Vertical	Diagonal M	$D_p = \frac{D = 8{,}700{,}000}{2\,M}$
A	.5	.375	.625	7,000,000
B	.5	.5	.707	6,200,000
C	.5	.75	.903	4,800,000
LA3	1.0	.5625	1.15	3,800,000
LC1	1.0	.25	1.03	4,200,000
LB1	1.0	.375	1.07	4,100,000

An examination of the curves is rather illuminating. It is seen that the strain curves determined by D_p correspond fairly closely with the strains measured over a zone included between the pin points. The strain curve determined by D shows the deformation of the weld itself, and is in all cases lower, but steeper than that of the zone. It is significant to note that in the short 2¼-in. welds the ratio of the maximum strain to the average strain does not exceed 2, but that for the longer 7-in. welds the ratio is greatly increased, varying from 2.52 to 3.68.

The strain measurements taken across the bars offered an excellent means to check the value of D and the correctness of the shear equations used to produce the curves in Figs. 12-15, as well as the theory of internal stress (Appendix C).

These shear equations were substituted for f_1 (x) in Equation H of Appendix C, and the deformations across three sections of the bars were computed by means of Equation R for the 1930 specimens. Computations were made for sections 3/16, 3½ and 6⅞ in. from the top, or end, of the joint bars. (Sections A, B and E).

The deformations are shown in Fig. 16 for specimen LC1, in which the theoretical deformations are shown as continuous smooth curves, and the measured deformations by solid circles. The correspondence was very satisfactory.

Length of Welds

When it became apparent that the length of the weld greatly affects the ratio of the maximum to the average shear, this ratio becoming greater as the length increases, it seemed highly desirable to develop a simple, practical method of determining the length of welds such that the maximum shearing stress would not exceed the average design stress by more than any desired ratio.

It is common practice to design welded joints with an average safety factor of 4. If it is desired that at no point should this factor fall below 2, then the maximum stress should not exceed twice the average. This was the limit set in deriving the rule, the derivation of which is as follows:

Let $R = \frac{\text{greater effective area} = a}{\text{smaller effective area}}$

and as a consequence R is always greater than unity.

then $b = \sqrt{\frac{a\,E}{(R+1)DN}}$

Twice the average shear was then equated to the maximum shear

$$2.\ \frac{P}{zN} = \frac{P}{bN\,(R+1)} \left(\frac{R \cosh \frac{z}{b} + 1}{\sinh \frac{z}{b}} \right)$$

$$\therefore\ \frac{z}{b} = \frac{2\,(R+1) \sinh \frac{z}{b}}{R \cosh \frac{z}{b} + 1}$$

By means of trial the equation was solved for $\frac{z}{b}$ for different values of R.

Since E and D are constants and for this case N = 4,

$$b = K_1 \sqrt{\frac{a}{R+1}}$$

and

$$Z = K_2 \sqrt{\frac{a}{R+1}}$$

The curve was then plotted, and is shown in the upper half of Fig. 17, with K as ordinates for values of R as abscissae, in which

$$Z = K\sqrt{a}$$

Now in order to design a joint in which the maximum shear shall not exceed twice the average, let the designer determine from the conditions of his particular problem, the gross areas of his bars and the length of weld needed to carry the load at usual working stresses.

From the lower curve of Fig. 17 determine the effective areas of the bars and compute $R = \frac{\text{larger area} = a}{\text{smaller area}}$

Then enter the upper curve with R and determine K, which when multiplied by the square root of the larger effective area a, will give the permissible length of weld, Z. If the designed length is smaller, the joint is satisfactory; if longer, either the width of the bars should be reduced, or the weld made larger in cross-section, thus reducing its length.

To illustrate, let it be desired to check the length of the welds in Series C, without having any previous knowledge of the shear distribution.

Z = 2.25, Joint bars 2 x ¾-in., Grip bar 3 x ½-in.

Joint Bars. $F_1 = 1, \frac{F}{Z} = .445$, efficiency = 67 per cent

$$a_1 = .67\ (A_1) = .67\ (3.0) = 2.01 \text{ sq. in.}$$

Grip Bar

Portion between welds, $F_1 = 1$; $\frac{F}{Z} = .445$, efficiency = 67 per cent

Projecting portion, $F_2 = .5$; $\frac{F}{Z} = .222$, efficiency = 89 per cent

$$a_2 = .67\ (1.0) + .89\ (.5) = .67 + .45 = 1.12 \text{ sq. in.}$$

$$R = \frac{2.01}{1.12} = 1.795$$

From upper curve $R = 1.795$ $K = 1.59$

$$\text{length } Z = 1.59\sqrt{2.01} = 1.59\ (1.416) = 2.25 \text{ in.}$$

Thus this weld is just the right length and should therefore cause a maximum stress of twice the average. Referring to the curve for Series C in Fig. 12, in which the shearing deformations of the weld itself are plotted, it is seen that the ratio of maximum to average shear is 610 to 307, or 1.99.

The authors wish to thank Professor J. Hammond Smith and his associates for kind permission to use the results of the thesis quoted herein, and particularly to express to Mr. F. T. Llewellyn their appreciation for his many valuable suggestions and for making available the experimental data used in this paper.

The following are attached as appendices:

Appendix A.—The notation used throughout the paper and in Appendices B and C.

Appendix B.—Several equations for the shear distribution along welds (Troelsch).

Appendix C.—The theoretical analysis of the direct stress and shearing stress at any point in a rectangular body.

APPENDIX A

The following is the notation used throughout the paper and in the equations of Appendix B and C:

E = 29,000,000 #/sq. in. = Modulus of elasticity in tension and compression
G = 2/5 E = 11,600,000 #/sq. in. = Modulus of elasticity in shear
D = 3/4 G = 8,700,000 #/sq. in. = Detrusion Ratio of isosceles right angle fillet
P = total external load on joint
p = intensity of direct stress in bar
V = total shear on weld
v = shear per unit of length of weld
s = intensity of shear in bar
q = shearing deformation of weld
Δ = deformation of any point in bar
A_1 = gross area of joint bars
A_2 = gross area of grip bar
a_1 = effective area of joint bars
a_2 = effective area of grip bar
a = larger of two effective areas, a_1 or a_2
r = ratio of effective areas $\frac{a_1}{a_2}$
R = ratio of larger to smaller effective area, > 1
L = length of joint bar
z = length of weld
F = distance from weld to axis of zero shear in bars
T = throat of weld
M = diagonal distance between pin points
N = number of welds in cross-section of joint

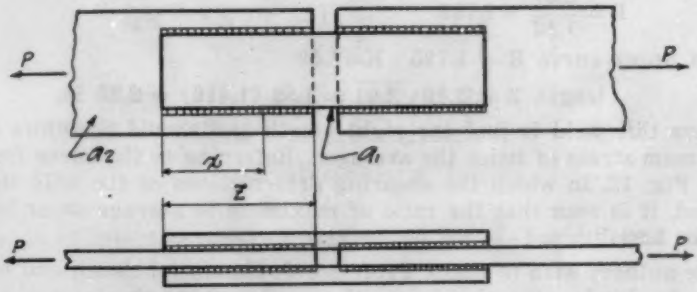
$b = \sqrt{\frac{a_1 a_2 E}{(a_1+a_2) ND}}$ = constant for joint, determining the shape of the shear curve

n = the number of the term in a Fourier Series

a_n, b_n, k_n, = coefficients in a Fourier Series.

APPENDIX B

Equations For Shear Distribution Along A Weld.



Shear at any point, x

$$v = \frac{P a_1}{bN(a_1+a_2)} \left\{ \frac{a_1 \cosh \frac{z}{b} + a_2}{a_1 \sinh \frac{z}{b}} \times \cosh \frac{x}{b} - \sinh \frac{x}{b} \right\} \ldots (I)$$

or

$$v = \frac{Pr}{bN(r+1)} \left\{ \frac{r \cosh \frac{z}{b} + 1}{r \sinh \frac{z}{b}} \times \cosh \frac{x}{b} - \sinh \frac{x}{b} \right\} \ldots (II)$$

Maximum values of v, When $x = 0$

$$v_0 = \frac{P}{bN(a_1+a_2)} \left\{ \frac{a_1 \cosh \frac{z}{b} + a_2}{\sinh \frac{z}{b}} \right\} \ldots (III)$$

When $x = z$

$$v_z = \frac{P}{bN(a_1+a_2)} \left\{ \frac{a_2 \cosh \frac{z}{b} + a_1}{\sinh \frac{z}{b}} \right\} \ldots (IV)$$

For the special case $a_1 = a_2$

$$v_0 = v_z = \frac{P}{2bN} \left\{ \frac{\cosh \frac{z}{b} + 1}{\sinh \frac{z}{b}} \right\} \ldots (V)$$

Expressions for the shear, v, to be published by the Bureau of Standards can be put into the form given above by a change in the origin of co-ordinates. These expressions were also independently derived by W. H. Weiskopf and for the special case, $a_1 = a_2$, by the late Professor Gillespie.

APPENDIX C

SHEET 1

APPENDIX C

Equations for the direct stress and shearing stress at any point in a rectangular body are derived as follows :-

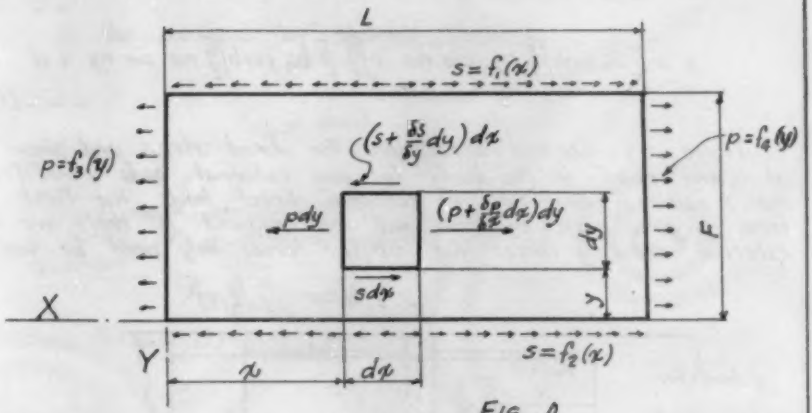


FIG. A.

FIG. A represents a rectangular body of unit thickness acted upon by direct stress on two faces and shearing stress o the other two. These external forces can vary with x and y according to any laws whatsoever, and are here represented by $f_1(x)$, $f_2(x)$ and $f_3(y)$, $f_4(y)$. p is the intensity of direct stress at any point, and s is the intensity of shear. Then

$$-p\,dy + s\,dx + (p + \frac{\delta p}{\delta x} dx)\, dy - (s + \frac{\delta s}{\delta y} dy)\, dx = 0$$

which reduces to

$$\frac{\delta p}{\delta x} - \frac{\delta s}{\delta y} = 0 \quad - - - - - (A)$$

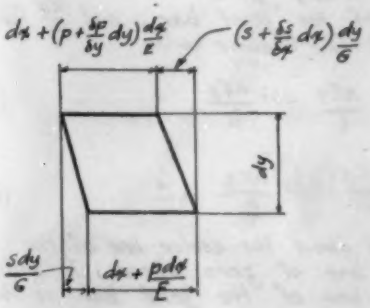


FIG. B

FIG. B represents the same differential area, dx dy, after deformation. From the figure

$$\frac{s dy}{G} + dx + \frac{p dx}{E} = dx + (p + \frac{\delta p}{\delta y} dy) \frac{dx}{E} + (s + \frac{\delta s}{\delta x} dx) \frac{dy}{G}$$

Which reduces to

$$\frac{\delta p}{\delta y} + \frac{\delta s}{\delta x} \times \frac{E}{G} = 0 \quad - - - (B)$$

APPENDIX C

SHEET 2

The following expressions for p and s satisfy the differential equations (A) and (B).

$$p = \sqrt{\frac{E}{G}} \sum a_n \cosh \sqrt{\frac{E}{G}}\, ny \sin n\alpha + \sum b_n \sinh \sqrt{\frac{G}{E}}\, n\alpha \cos ny + c \qquad \text{- - - (C)}$$

$$s = \sum a_n \sinh \sqrt{\frac{E}{G}}\, ny \cos n\alpha + \sqrt{\frac{G}{E}} \sum b_n \cosh \sqrt{\frac{G}{E}}\, n\alpha \sin ny + d \qquad \text{- - - (D)}$$

These are general expressions for direct stress and shear at any point in the body for any external loads parallel to the X axis. If there are no external direct loads the first term only in each equation will be required. If there are no external shearing forces the last two terms only need be used.

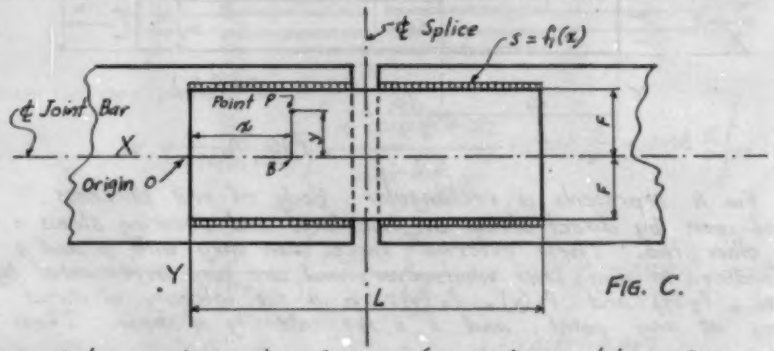


FIG. C.

Let us apply equations (C) and (D) to the joint bar of a side welded tension splice, as shown in FIG. C. Since there are no external direct stresses only the first two terms in the equations need be used. To satisfy the two conditions

when $x = 0$, $p = 0$

when $x = L$, $p = 0$

take the Y axis at one end of the joint bar; put $\frac{\pi x}{L}$ for x and $\frac{\pi y}{L}$ for y. Then (C) and (D) become

$$p = \sqrt{\frac{E}{G}} \sum a_n \cosh \sqrt{\frac{E}{G}}\, \frac{n\pi y}{L} \sin \frac{n\pi x}{L} \qquad (E)$$

$$s = \sum a_n \sinh \sqrt{\frac{E}{G}}\, \frac{n\pi y}{L} \cos \frac{n\pi x}{L} \qquad (F)$$

If the splice is symmetrical about the center line of the joint bar, this center line is a line of zero shear. To satisfy this condition take the center line of the joint bar as the X axis. Then when $y = 0$, $s = 0$.

APPENDIX C

SHEET 3

We still have to satisfy the condition that when $y = F$, $s = f_1(x)$. Put $y = F$ in equation (F). Then

$$s = \sum a_n \sinh\sqrt{\frac{E}{G}}\frac{n\pi F}{L}\cos\frac{n\pi x}{L}$$

Then by the methods of Fourier Series

$$a_n = \frac{\frac{2}{L}\int_0^L f_1(x)\cos\frac{n\pi x}{L}\,dx}{\sinh\sqrt{\frac{E}{G}}\frac{n\pi F}{L}} \qquad \text{-------- (G)}$$

It is found more convenient for computation to express (E) and (F) in terms of a new series of coefficients k_n given by the equation

$$k_n = \frac{2}{L}\int_0^L f_1(x)\cos\frac{n\pi x}{L}\,dx \qquad \text{--------- (H)}$$

Equations (E) and (F) then become

$$p = \sqrt{\frac{E}{G}}\sum k_n \frac{\cosh\sqrt{\frac{E}{G}}\frac{n\pi y}{L}}{\sinh\sqrt{\frac{E}{G}}\frac{n\pi F}{L}}\sin\frac{n\pi x}{L} \qquad \text{-----(K)}$$

$$s = \sum k_n \frac{\sinh\sqrt{\frac{E}{G}}\frac{n\pi y}{L}}{\sinh\sqrt{\frac{E}{G}}\frac{n\pi F}{L}}\cos\frac{n\pi x}{L} \qquad \text{-------(L)}$$

The deformation of any point measured parallel to the X axis is obtained as follows:
The deformation on the line OB (See Fig. C) is

$$\Delta_{OB} = \int_0^x \frac{p\,dx}{E} = \frac{L}{\pi\sqrt{EG}}\left[-\sum\frac{a_n}{n}\cos\frac{n\pi x}{L} + \sum\frac{a_n}{n}\right]$$

The deformation on the line BP is

$$\Delta_{BP} = \int_0^y \frac{s\,dy}{G} = \frac{L}{\pi\sqrt{EG}}\left[\sum\frac{a_n}{n}\cosh\sqrt{\frac{E}{G}}\frac{n\pi y}{L}\cos\frac{n\pi x}{L} - \sum\frac{a_n}{n}\cos\frac{n\pi x}{L}\right]$$

APPENDIX C

SHEET 4

$$\Delta = \Delta_{BF} - \Delta_{OB} = \frac{L}{\pi\sqrt{EG}}\left[\sum \frac{a_n}{n}\cosh\sqrt{\frac{E}{G}}\frac{n\pi y}{L}\cos\frac{n\pi x}{L} - \sum\frac{a_n}{n}\right] \qquad \text{--------(M)}$$

It is found that when the external loads on the joint bar are symmetrical about the center line of the splice, a_n equals zero for even values of n. For odd values of n from equation (M) when $x = \frac{L}{2}$

$$\Delta_{\frac{L}{2}} = -\frac{L}{\pi\sqrt{EG}}\sum\frac{a_n}{n} \qquad \text{---------(N)}$$

regardless of the value of y. This means that the centerline of the splice is still a straight line after deformation and moves with reference to the origin a distance given by equation (N).

Let us take the centerline of the splice as the reference line for measuring deformations. (Note that coordinates are still measured as shown in Fig. C.) Equation (M) then becomes

$$\Delta = \frac{L}{\pi\sqrt{EG}}\sum\frac{a_n}{n}\cosh\sqrt{\frac{E}{G}}\frac{n\pi y}{L}\cos\frac{n\pi x}{L} \qquad \text{----(P)}$$

Using k_n instead of a_n

$$\Delta = \frac{L}{\pi\sqrt{EG}}\sum\frac{k_n}{n}\frac{\cosh\sqrt{\frac{E}{G}}\frac{n\pi y}{L}}{\sinh\sqrt{\frac{E}{G}}\frac{n\pi F}{L}}\cos\frac{n\pi x}{L} \qquad \text{-----(R)}$$

When $y = F$, the deformation at the weld is

$$\Delta = \frac{L}{\pi\sqrt{EG}}\sum\frac{k_n}{n}\frac{\cos\frac{n\pi x}{L}}{\tanh\sqrt{\frac{E}{G}}\frac{n\pi F}{L}} \qquad \text{---------(S)}$$

Magnetic Testing of Butt Welds*

T. R. WATTS†

1. MAGNETOGRAPHIC INSPECTION, OR MAGNETIC SPECTRA. NEW VARIATIONS OF THE METHOD.

THERE have been several publications in French and English describing the magnetic method of testing welds developed by M. Roux, head of the Laboratory of La Soudure Autogene Francaise. This method consists of passing magnetic flux through the weld and obtaining a picture of the leakage flux by sifting iron filings on to a piece of paper placed on the weld. These pictures are called magnetographs or magnetic spectra. An excellent description of the method appeared in the February issue of *The Welding Engineer*.[1]

The magnetographic method has been employed experimentally by the Research Laboratories of our company for nearly two years, during which several minor variations and improvements have developed, as described in this paper.

The electro-magnet used for getting a flux through the welded structure is preferably placed on the under-side of the welded plate, bridging the weld, and very fine particles of iron are sifted upon a piece of paper laid on the weld as shown in Fig. 1. Cracks, blow-holes, poor fusion, or similar faults offer higher reluctance (magnetic resistance) to the flux, and are indicated by a dense collection of fine particles of iron directly over the fault.

Electro-Magnet Details

The cores of our electro-magnets for weld testing are now built of a stack of strips of silicon-steel sheets, bent into a semi-circular or horseshoe shape and bolted together only at the middle, leaving the ends of the strips loose and flexible. This construction allows the magnet poles to conform snugly to the surface of a welded plate which is not straight, thus greatly reducing the air-gap reluctance between the magnet and plate, thereby decreasing the number of ampere-turns required and allowing use of smaller coils.

Two or four coils are used on each magnet, the coils being d.c. motor field coils, usually, wound for 55 volts per coil. This arrangement is very convenient, as these coils can be connected in parallel for operation from an arc-welding generator, or two coils in series for the common 110 to 125 volt d.c. mains, or four coils in series for 220 to 250 volt d.c. mains. Desirable auxiliaries are a rheostat, a field discharge resistor, and a small switch on the magnet arranged so that a man can operate the switch with one finger while he supports the magnet in his hands to put it on or take it off of a weld.

*Paper to be presented at Fall Meeting of the A. W. S., Chicago, September, 1930.
†Research Laboratories, Westinghouse Elec. & Mfg. Co.
[1] Magnetic Testing of Welds. The Welding Engineer, February, 1930. Pages 31-35.

Iron Powder Instead of Filings

We use a very fine iron powder, reduced by hydrogen, principally because it is easily available from chemical supply houses, and is easily distributed uniformly by sifting it from a sort of pepper shaker having very small holes. It is quite satisfactory, but not necessarily better than good iron filings.

Magnetographs on Blueprint or Van Dyke Paper

If a magnetograph is to be permanently recorded, a piece of blueprint or Van Dyke paper is used on the weld, and as soon as the magnetograph is formed by the iron powder or filings, a print is made by holding a small portable therapeutic arc-lamp over it, as shown in Fig. 1. If possible,

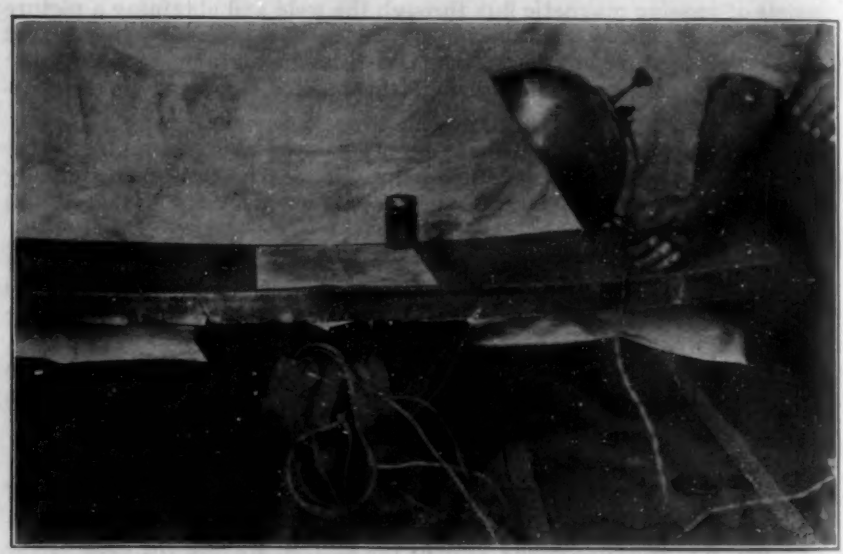


FIG. 1—METHOD OF MAKING AND RECORDING MAGNETOGRAPHS. ELECTRO-MAGNET HAVING FLEXIBLE LAMINATED CORE, AND PORTABLE ARC LAMP FOR EXPOSING PRINTING PAPER

the magnet is turned off before the print is made, so that the strings of iron filings fall flat against the paper and print more sharply. If the paper is not in a horizontal position and the magnet has to be left on to hold the filings in place, the arc-lamp should be held in a fixed position while making the print. The paper should be held down by strips of brass, or otherwise, to prevent curling while printing.

If a single print is sufficient and a negative impression is satisfactory, blueprint paper serves very well, and requires only about thirty seconds exposure at about 10 in. from the portable arc-light described later.

However, much better results are obtained by making the original magnetograph on Van Dyke paper (thin brown-print paper) which can then be used the same as a photograph negative, to make as many positive prints as desired. The Van Dyke paper requires about three times as much exposure as the blueprint paper. Both are slow enough so

that they will not be fogged by ordinary indoor illumination in the minute or two required to sift the iron powder on to the paper. Both

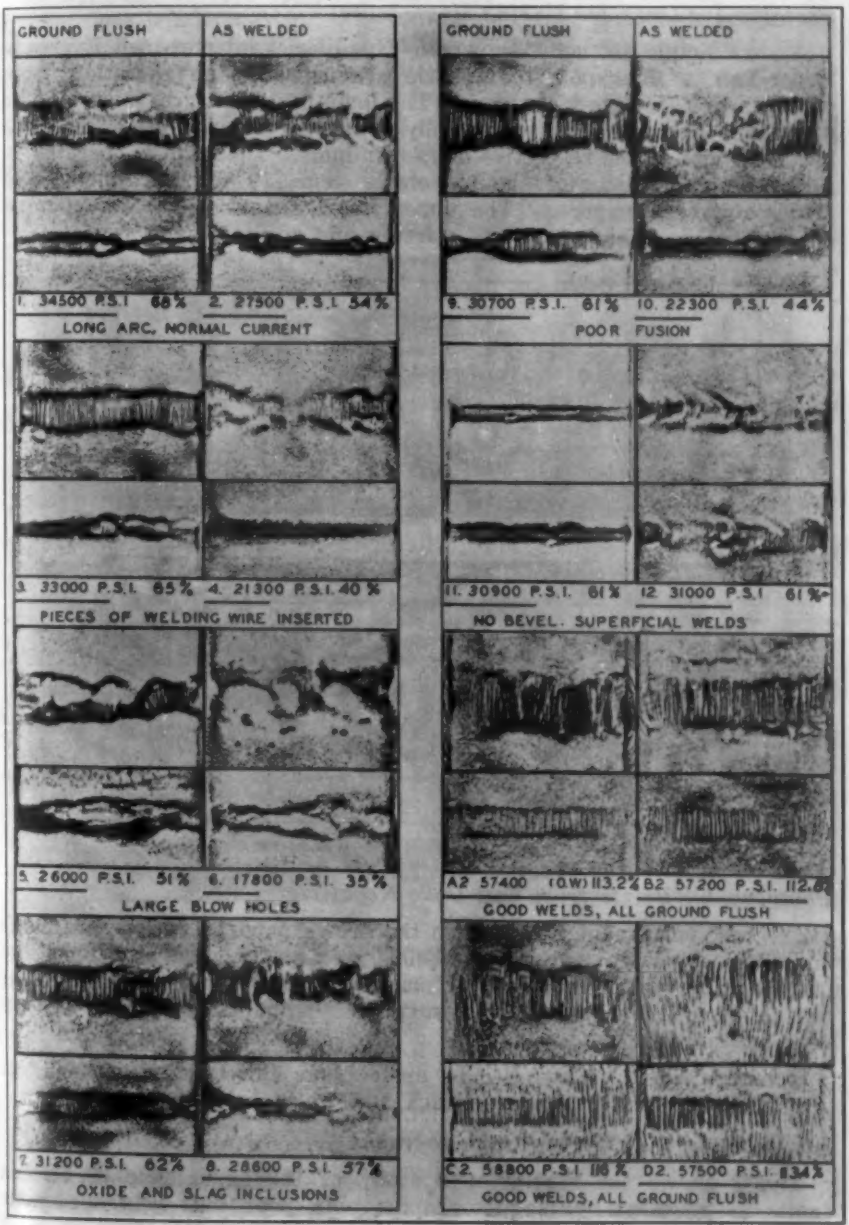


FIG. 2—MAGNETOGRAPHIC DIAGNOSIS OF WELDING FAULTS. TOPS AND BOTTOMS OF V BUTT WELDS IN ½-IN. MILD STEEL PLATE, BY MANUAL ARC-WELDING WITH BARE ELECTRODE. THIRTY-DEG. MACHINED BEVELS, EXCEPT IN PIECES 11 AND 12

can be finished satisfactorily by merely washing thoroughly in clean water.

Portable Arc Lamp for Making Magnetograph Negatives

A very simple arc lamp, shown in Fig. 1, uses quarter-inch Eveready Super-Tan or Stackpole therapeutic arc carbons, the radiation from which is rich in ultra-violet rays. The lamp has twin arcs, in series, the upper two carbons being electrically connected to each other, and the lower carbons to the respective lamp terminals. The lamp is operated in series with a resistor of about 5 ohms, on a 110 volt a.c. supply, and draws about 10 amperes. The upper two carbon holders are mounted on stiff hinges, which facilitate starting and adjusting the arcs.

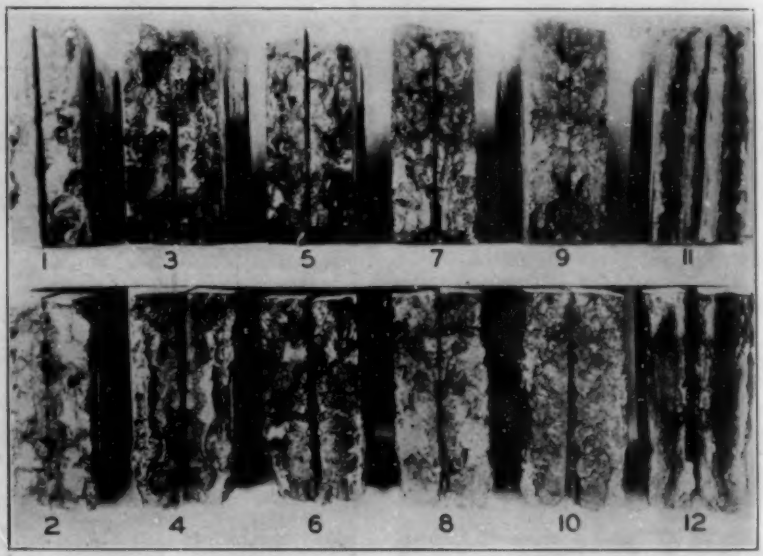


FIG. 3—FRACTURES OF POOR WELDS OF FIG. 2

Photographic Prints from Van Dyke Negatives

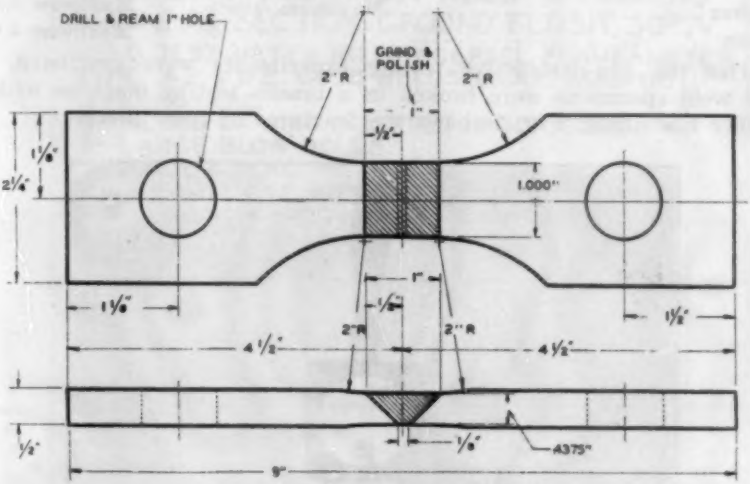
The best permanent prints from the brown paper negatives are made on a very "hard" or "outline special" photographic paper. They are printed in a regular photographic printing machine with an exposure of five seconds or less, and show a surprising amount of detail not easily seen on the negative.

Blueprint positives can also be made from Van Dyke negatives, but are not so satisfactory as the black and white prints.

Diagnosis of Welds from Magnetographs

Fig. 2 shows the results of a study of the appearance of certain faults as revealed by magnetographs. Six poor butt-weld specimens ½-in. x 5 in. x 9 in. were made, each having a certain type of fault as tabulated in Table 1. Each of these specimens was then milled in

two, making two ½ in. x 2⅜ in. x 9 in. specimens presumably alike, one of which, bearing an odd number, had the weld surface ground flush with the surface of the plate, while the other, bearing an even number, was left as welded. For comparison, four good weld specimens were included, each from a different piece. These four good welds were



WELDED TENSILE TEST PIECE

FIG. 4

all ground flush, because magnetographs made on the rough surface as welded are not sensitive to minor faults. The specifications for the welding are given in Table I.

TABLE I

SPECIFICATIONS FOR WELDING TEST SPECIMENS

All V Welds, with 30° Machined Bevel, except Numbers 11 and 12)

Specimen Number	Welding Specifications
1 & 2	Long arc, but normal current.
3 & 4	Pieces of 3/16-inch welding wire inserted to fill in.
5 & 6	Blow-holes in weld.
7 & 8	Oxide and slag inclusions.
9 & 10	Incomplete fusion. Current too low.
11 & 12	No bevel. Weld both sides. Insufficient penetration.
A2, B2, C2 & D2	Good welds, each from different specimen.

The specimens were made from hot-rolled open-hearth steel bars, and welded with bare electrode.

The specifications regarding composition of the materials used are given in Table II.

TABLE II

SPECIFICATIONS OF MATERIALS

	Steel Bars	Welding Wire
Carbon	0.08 to 0.18%	0.12 to 0.18%
Manganese	Maximum 0.55%	0.40 to 0.55%
Phosphorus	Maximum 0.05%	Maximum 0.05%
Sulphur	Maximum 0.06%	Maximum 0.05%
Silicon		Maximum 0.08%

After the non-destructive testing experiments were completed, the poor weld specimens were broken in a tensile testing machine without further machining. Fig. 3 shows the fractures of these pieces.

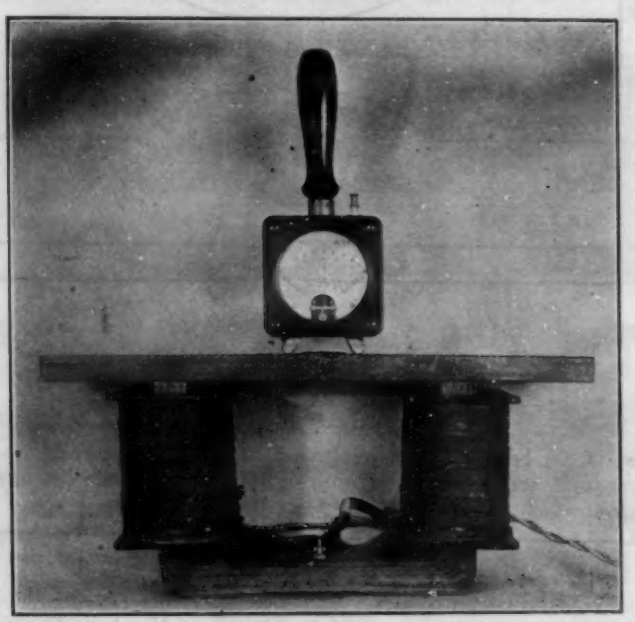


FIG. 5—LABORATORY TEST METHOD, USING WELD TEST METER NO. 1

The good weld specimens were machined to tensile test pieces designed to insure breaking at the weld, as shown in Fig. 4.

Four tensile test pieces like Fig. 4 were also made without any weld, to compare the tensile strength of the parent metal alone. They were stamped A, B, C, and D, being from the same bars as the good weld specimens A2, B2, C2 and D2 respectively.

In calculating the tensile strength in pounds per square inch, the pieces tested as welded (slightly reinforced) were considered as ½ in. thick; while the specimens ground flush and the machined test pieces were calculated on the basis of careful measurements of the actual sectional area at the weld. The tensile test results on the various specimens are given in Tables III, IV, and V.

Conclusions Regarding Magnetographic Inspection

From the experiments reported above and many others, we believe that magnetographic inspection is a valuable means of discovering

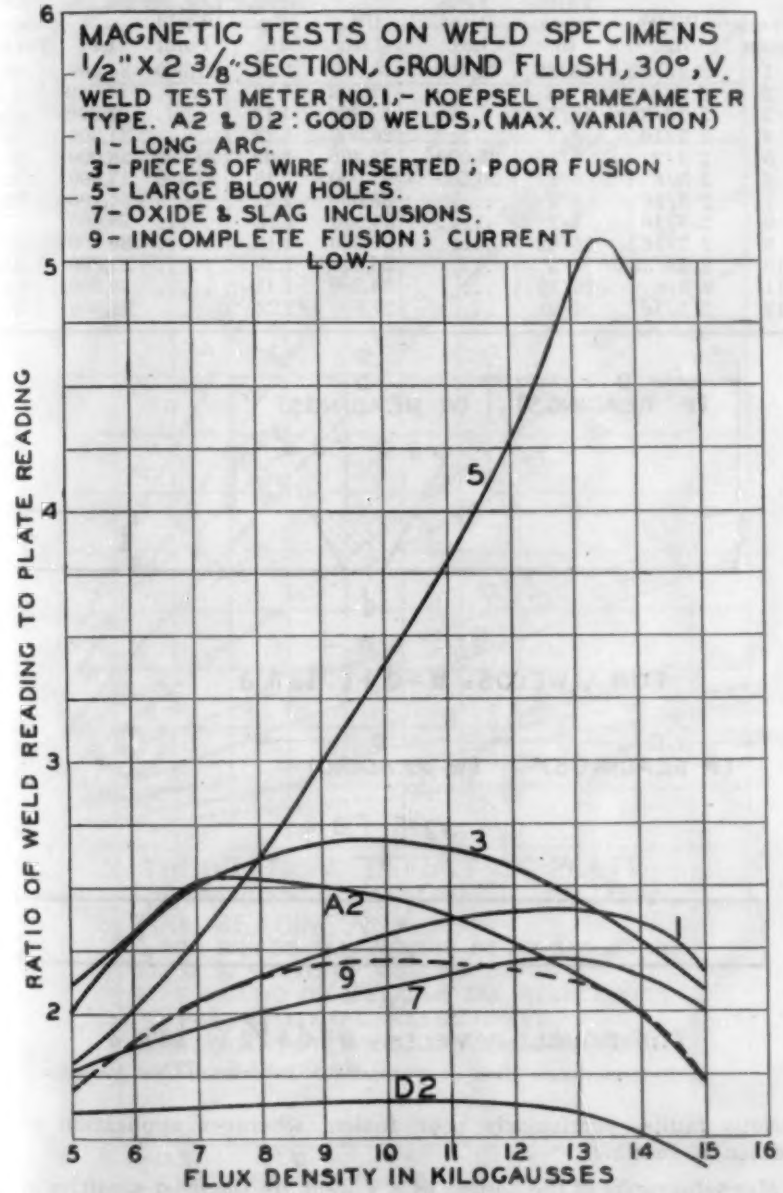


Fig. 6—Weld Test Meter Ratio vs. Flux Density. For Test Specimens Described in Table I

TABLE III

TENSILE TEST RESULTS ON POOR WELD SPECIMENS

(Odd numbers ground flush; even numbers as welded)

Specimen	Width, In.	Thickness, In.	Yield Point, Lbs.	Ult., Lbs.	Area, Sq. In.	Lbs. per Sq. In. Yield Point	Lbs. per Sq. In. Ult.	Efficiency, Per Cent
1	2 15/32	15/32	37,000	40,000	1.16	31,900	34,500	68.
2	2 3/8	1/2	.....	32,500	1.18	.....	27,500	54.
3	2 13/32	15/32	.....	37,300	1.13	.....	33,000	65.
4	2 7/16	1/2	.....	26,000	1.22	.....	21,300	40.
5	2 1/2	7/16	25,000	28,400	1.09	23,000	26,000	51.
6	2 3/8	1/2	20,500	21,000	1.18	17,400	17,800	35.
7	2 7/16	1/2	.....	38,050	1.22	.....	31,200	62.
8	2 7/16	1/2	.....	34,900	1.22	.....	28,600	57.
9	2 7/16	15/32	.....	35,300	1.15	.....	30,700	61.
10	2 13/32	1/2	.....	26,800	1.20	.....	22,300	44.
11	2 3/8	15/32	.....	34,300	1.11	.....	30,900	61.
12	2 7/16	1/2	.....	37,800	1.22	.....	31,000	61.

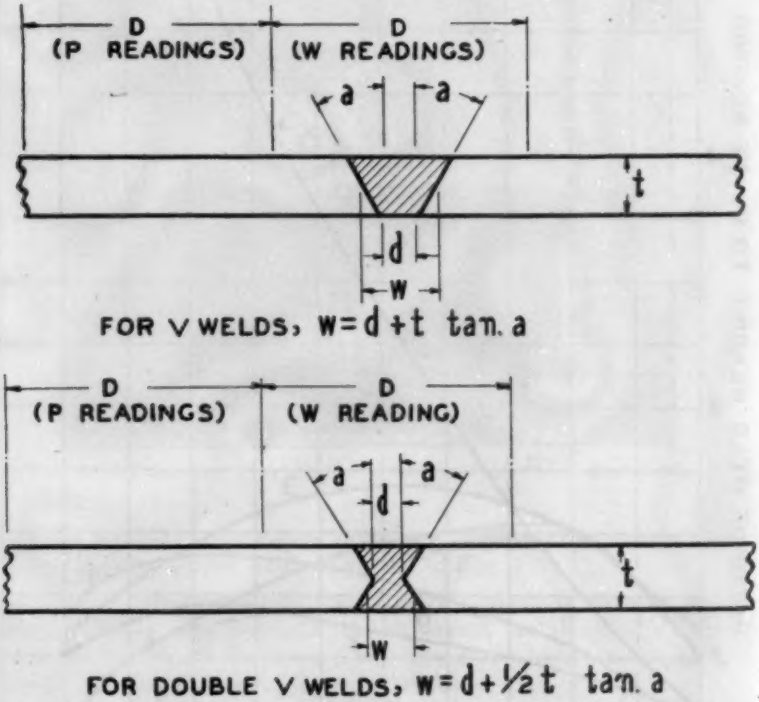


FIG. 7—DIMENSIONS USED IN THEORETICAL DISCUSSION AND FORMULA

serious faults, particularly poor fusion, wherever application of the method is feasible.

Magnetographs of the bottom of a V weld are the most sensitive of any that are ever practicable under usual shop conditions, because poor fusion

is most likely to be at the bottom of the V, and little or no reinforcement is there to interfere with the results.

Magnetographs made on a rough surface, as welded, are not sensitive enough to reveal anything less than a very serious fault.

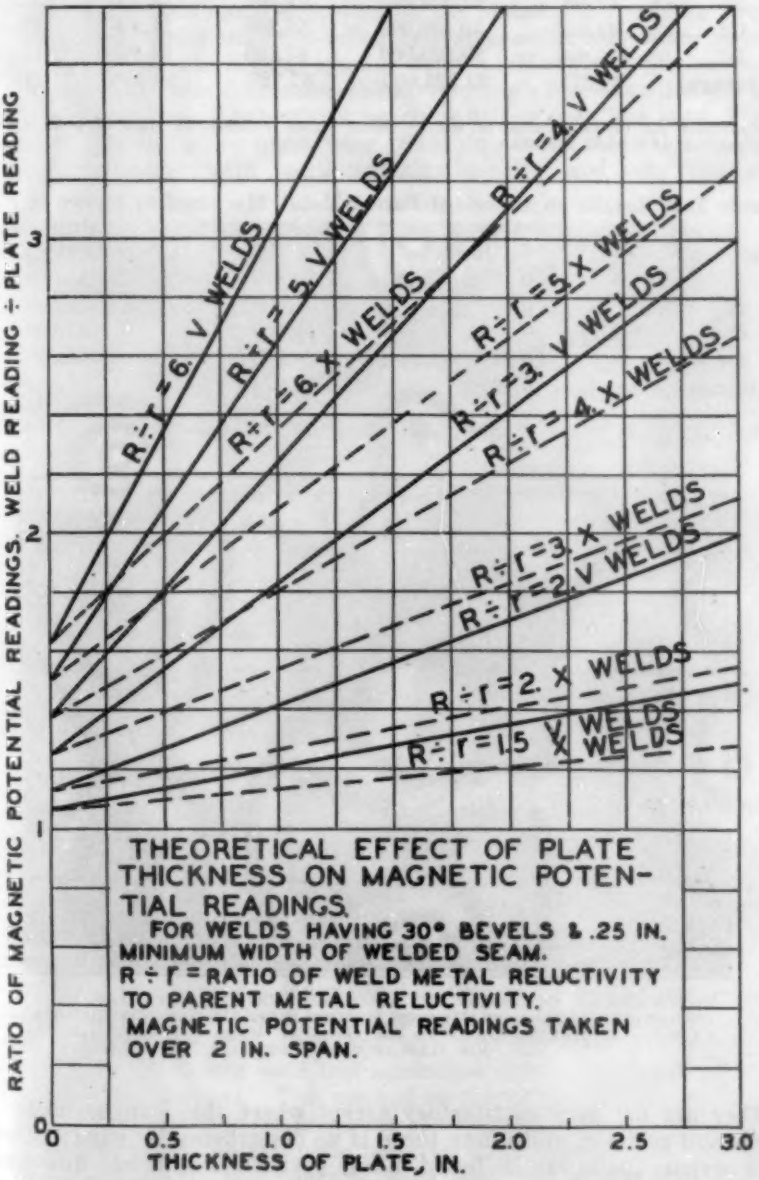


FIG. 8—THEORETICAL EFFECT OF THICKNESS OF PLATE AND TYPE OF WELD. FOR POTENTIAL READINGS OVER A 2-IN. SPAN

TABLE IV

Tensile Test Results on Good Weld Specimens, Machined as Shown in Fig. 4

Specimen	Yield Pt., p. s. i.	Modulus of Elasticity	Ultimate p. s. i.	Elongation in 1 In.	Efficiency, Per Cent
A2	39,900	28,600,000	57,400*	24.6%	113.2
B2	42,400	29,000,000	57,200	17.1%	112.8
C2	41,600	30,400,000	58,800	11.1%	116.0
D2	41,600	29,300,000	57,500	13.4%	113.4
Average	41,375	29,325,000	57,725	16.55%	113.8

*Specimen A2 broke outside of weld. Other three broke near edge of weld, through both parent and weld metals.

TABLE V

Tensile Test Results on Unwelded Parent Metal, Machined as Shown in Fig. 4

Specimen	Area, Sq. In.	Yield Point, p. s. i.	Ultimate Strength, p. s. i.
A	0.438	30,100	50,800
B	0.435	31,000	50,800
C	0.437	31,000	50,800
D	0.438	30,500	50,200
Average	0.437	30,675	50,650*

*This value was used as 100 per cent in figuring "efficiencies" in Tables III and IV.

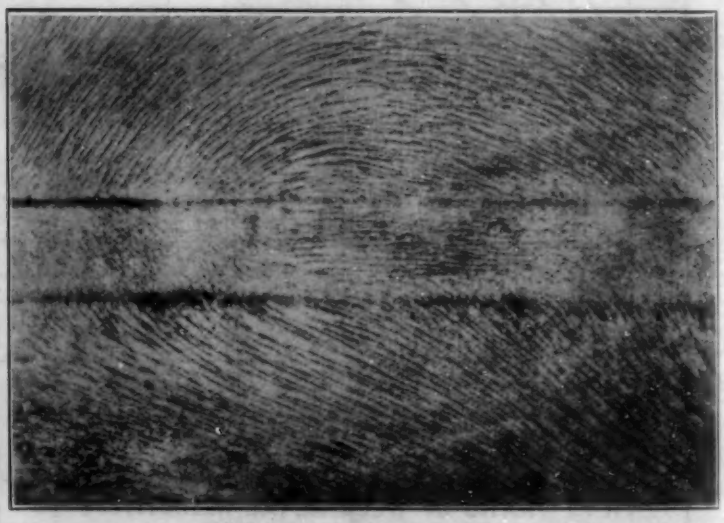


FIG. 9—THIRD DIMENSION MAGNETOGRAPH SHOWING LEAKAGE FLUX DISTORTION. CAUSED BY MAGNET HAVING RIGID CORE AND A CROOKED TEST PIECE, MAKING UNEQUAL AIR GAPS AT MAGNET POLES. LARGER AIR GAP AT THE RIGHT

They are not very satisfactory except where they can be made in a horizontal position, and where there is no disturbance by wind; although very serious faults can be found in any position if sufficient flux density is used.

II. WELD TESTING BY MEASUREMENT OF MAGNETIC POTENTIALS. THEORY OF THE METHOD

The principle underlying any magnetic weld test method is the fact that faults in welds increase their reluctance, or magnetic resistance.

Normal good weld metal deposited by the metallic arc welding process has higher reluctivity than hot-rolled mild steel plate, sometimes as much as four or five times as high at low flux density. However, with increasing flux density this ratio decreases, and at very high flux densities the good weld metal may have a reluctivity nearly equal, or even less than, that of the plate. On the other hand, poor welds do not decrease their relative reluctance so much with increasing flux density, and very bad welds

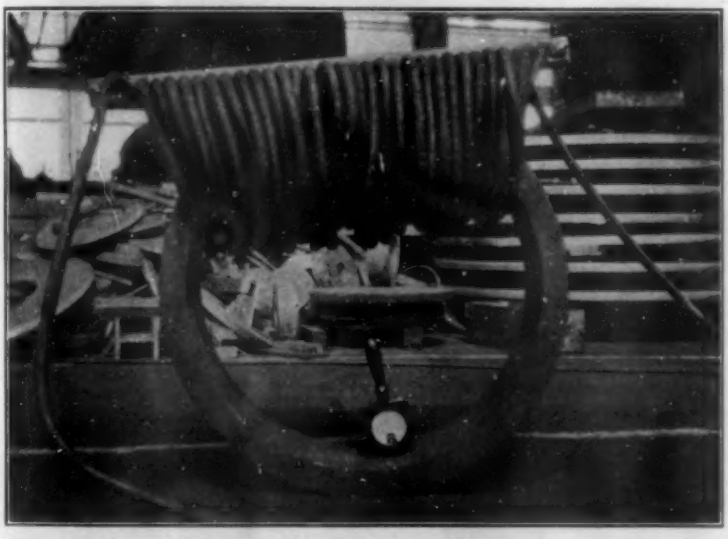


FIG. 10—SPLIT COIL FOR MAGNETIZING WELDED STRUCTURES. STRUCTURE MUST FORM A CLOSED MAGNETIC CIRCUIT. THIRTY TURNS OF EXTRA-FLEXIBLE CABLE ARE APPLIED SIMULTANEOUSLY

show an increase in relative reluctance, with increasing flux. At low-flux densities, up to about eight or ten kilogausses, there does not seem to be much difference in the reluctance of a good weld and a poor one, but at flux densities of twelve kilogausses or more the difference is quite perceptible.

Therefore, if we pass a magnetic-flux through a welded seam, in the same manner as for making magnetographs, but measure the magnetic-potential drop across the weld and also for the same distance in the parent metal, we have a weld test somewhat more quantitative than the magnetographic method. The method employed for laboratory tests is shown in Fig. 5. The same flux goes through the weld and the adjacent parent metal, hence the magnetic potential drop between any two points in proportional to the reluctance between those two points, and therefore is an indication of the quality of the weld.

Fig. 6 shows the variation of ratio of weld potential reading to adjacent parent metal reading in the case of the previously described five poor V welds ground flush, and the two good welds showing the greatest difference magnetically. Observe that above 13 kilogausses the poor welds read considerably higher than the good welds.

The above data are for the ½ in. by 2 3/8 in. test pieces. The ratio of weld reading to plate reading, taken with any given instrument, will vary with the thickness of the plate and type of joint.

For a theoretical consideration, refer to Fig. 7 representing welds which, for purposes of this discussion, are assumed to be ground flush, and to be homogeneous and perfectly fused to the parent metal.

FIG. 11—WELD TEST METER NO. 1. SIMPLIFIED KOEPSEL PERMEAMETER TYPE

Let d = width of narrowest part of weld.
a = angle of bevel.
t = thickness of plate.
w = average width of welded seam.

For V welds $w = d + t \tan a$

For double V welds $w = d + \frac{1}{2} t \tan a$

Let R = reluctivity of weld metal (under given conditions).
r = reluctivity of parent metal (under same conditions).
D = distance spanned by instrument reading magnetic potential.
W = reading of magnetic potential over distance D, including weld.
P = reading of magnetic potential over distance D, on adjacent plate.

Then the ratio of the weld reading W to the plate reading P is approximately:

$$\frac{W}{P} = 1 + \frac{w}{D}\left(\frac{R}{r} - 1\right)$$

Assuming the bevel, a, to be 30 degrees, and the narrowest width d to be one-quarter inch:

For V welds, $w = 0.25 + 0.5774\ t$

For double V welds, $w = 0.25 + 0.2887\ t$

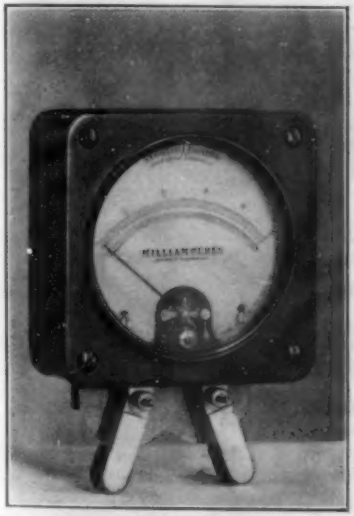


FIG. 12—WELD TEST METER NO. 2. FRONT VIEW. POLE PIECES ARE HINGED FOR ADJUSTING THE SPAN

FIG. 13—WELD TEST METER NO. 2. REAR VIEW. SHOWING BATTERY RHEOSTAT KNOB, AND DIAL FOR ADJUSTABLE POLE PIECES

For an instrument which reads the magnetic-potential between posts two inches apart, (D = 2 in.) the family of curves shown in Fig. 8 gives the approximate theoretical effect of different thicknesses of plate. for single V and double V welds, for reluctivity ratios (R ÷ r) of 1.5, 2, 3, 4, 5, and 6. These curves give an idea of what to expect, but are necessarily only rough approximations, since in practice there are many variables which could not all be considered in the theoretical curves. For example, no consideration is given to the greater density of flux at the bottom of a single V, or at the middle of a double V weld, or to the effect of the fusion zones, or of the varying amount of reinforcement, or of the annealing effect of each layer on the previous layers. Therefore, it

is necessary to make calibration curves for the instrument used, by means of a good specimen of the same material and type of weld as the welds to be tested.

Means of Producing Magnetic Flux

In practice, the necessary flux is usually produced most easily by means of a large electro-magnet having a flexible laminated core, as described in the first part of this paper, but having a somewhat greater span. The flexible core is even more desirable in this application, to prevent distortion of the leakage flux. Fig. 9 shows the distortion of flux caused by a rigid-core electro-magnet applied to a crooked specimen, making unequal air-gaps between the specimen and magnet, which cause unequal parent-metal readings on opposite sides of the welded seam. This Fig. 9 is a third dimension magnetograph, made on the edge of a test specimen by placing the magnet on its side and laying the Van Dyke paper on the edge of the specimen.

FIG. 14—MAGNETIC VANE TYPE OF WELD TEST METERS. MADE BY SIMPLE ALTERATIONS ON TYPE BT AMMETERS

In addition to reducing the required ampere-turns and permitting smaller coils, the laminated construction also facilitates the use of the magnet and the magnetic potential instrument on the same side of the plate, when necessary.

A wide core is desirable, so that the magnet will not have to be moved so frequently in testing a long welded seam.

When the welded structure is a ring, or forms a closed magnetic-circuit in itself, it may be entirely magnetized by winding it with several turns of welding cable, which is then connected to an arc-welding generator. Extra-flexible welding cables, in lengths of about 40 feet, are used in this method. Each length of cable is handled on a small spool or reel, and is equipped with knuckle-joint connectors, by which any end can be quickly and easily attached to any other end. The joints are easily insulated by slipping a piece of garden hose over the connectors.

If many tests of this type are to be made on structures of similar size, it may be worth while to construct split coils such as shown in Fig. 10. Each turn of cable has a plug and receptacle, so arranged that all of them can be pulled together or pushed apart simultaneously by hand screws in the ends of the terminal boards. Probably smaller and lighter units than the one shown would be more convenient, as this one is cumbersome and requires two men to handle it.

Instruments for Magnetic Testing of Welds

The method of testing welds by reading magnetic potentials was developed by I. F. Kinnard.[2] Mr. Kinnard read the magnetic potentials across the weld and for a similar span on the adjacent parent metal by means of two air-cored exploring coils, located in spaces between three soft iron posts placed in line on the welded plate. This method required the use of a delicate galvanometer unsuited to shop work, and readings had to be taken of the swing of the galvanometer when the magnetizing

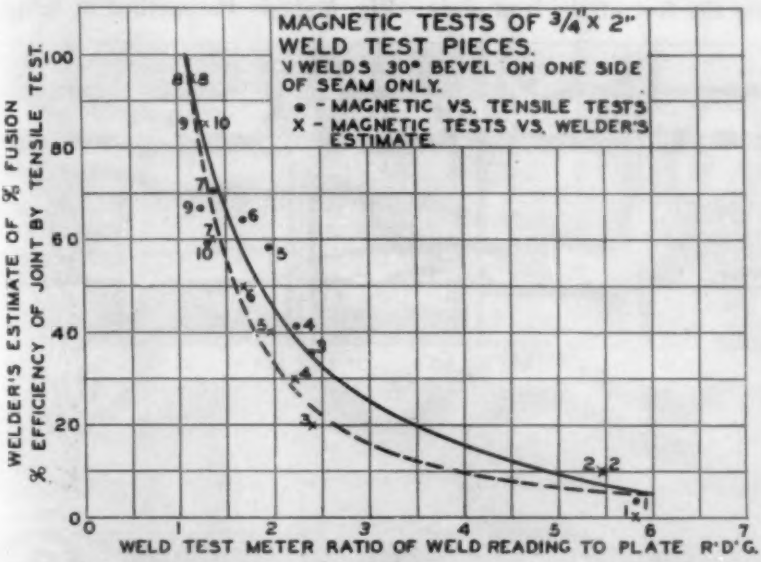


FIG. 15—WELD TEST METER READINGS VS. WELDER'S ESTIMATE AND TENSILE TESTS. FOR SPECIMENS DESCRIBED IN TABLE VI, AT CONSTANT MAGNETIZING FORCE

current was interrupted or reversed. This device resembles the means of reading magnetic potential employed by Frank P. Fahy in his simplex permeameter.[3]

The so-called Rogowski magnetic potentiometer[4] may also be used for weld testing. It consists of a non-magnetic core of uniform cross-section, usually flexible, wound uniformly along its entire length with magnet wire. When connected to a suitable galvanometer, such as a Grassot flux meter, it reads the magnetic potential between its ends, the magnetic flux being interrupted or reversed to take a reading. For weld-testing applications, where accuracy as a magnetic potentiometer is not required, much greater sensitivity may be had by substituting a semi-circular soft iron core, with non-magnetic spacers on the ends of the core.

The inconvenience of the above devices and methods led the writer to

[2] Method and Apparatus for Testing Welds. U. S. Patent No. 1,440,470. I. F. Kinnard, assignor to Westinghouse Elec. & Mfg. Co.

[3] Permeameter. U. S. Patent No. 1,511,595. Frank P. Fahy.

[4] Magnetic Potentiometer. U. S. Patent No. 1,204,489. W. Rogowski.

develop a direct reading instrument of more rugged construction. Fig. 11 shows the first weld test meter constructed, which is a simplified form of the old Koepsel potentiometer. It is made from a small d.c. voltmeter of the common d'Arsonval type, by removing the permanent magnet, substituting the legs or posts of non-residual steel, and placing a small flashlight battery and switch in the case, by means of which a constant current can be passed through the moving coil. The instrument now gives a reading proportional to the leakage flux diverted through its magnetic circuit, which is approximately proportional to the magnetic potential across the feet of the iron posts. Fig. 5 shows the method of taking a

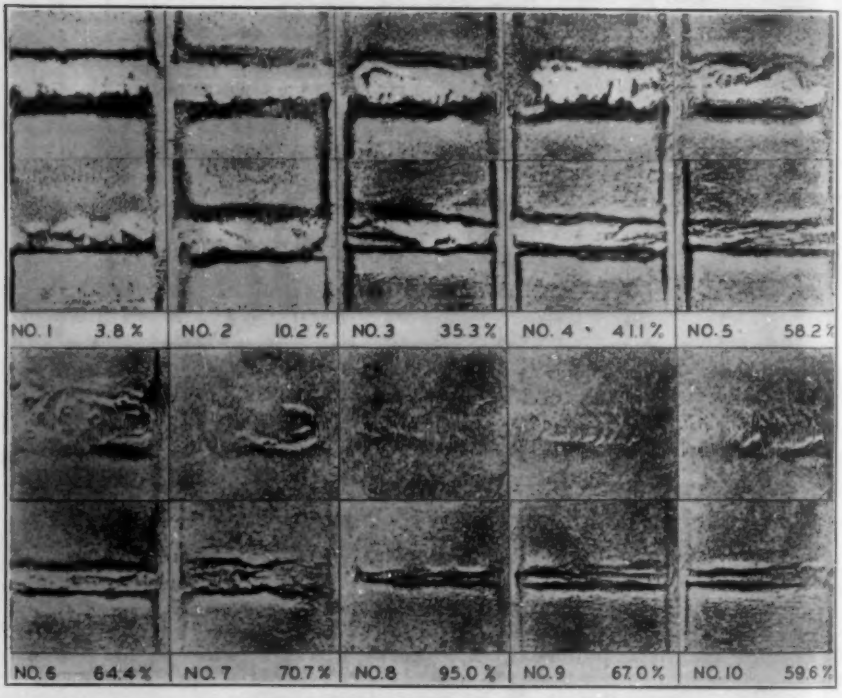


FIG. 16—MAGNETOGRAPHS OF VARIOUS DEGREES OF FUSION. FOR ¾ X 2-IN. PIECES DESCRIBED IN TABLE VI. THE PART OF EACH PIECE ON THIS SIDE OF THE WELD HAS NO BEVEL. OTHER PART HAS 30-DEG. BEVEL

weld reading, as employed in securing most of the experimental data here reported. The reading taken across the weld is compared with the reading on the adjacent parent metal. At the flux densities used, the previous magnetic history of the steel makes no appreciable difference. If any doubt exists on this point, simply reverse the flux direction before reading.

The special dial shown on the weld test meter permits a direct reading of the ratio of weld reading to parent-metal reading, since at any usable flux density the parent reading will be 1.0 on some scale on the dial, and therefore the weld reading, on the same scale, is the ratio of weld reading to parent-metal reading.

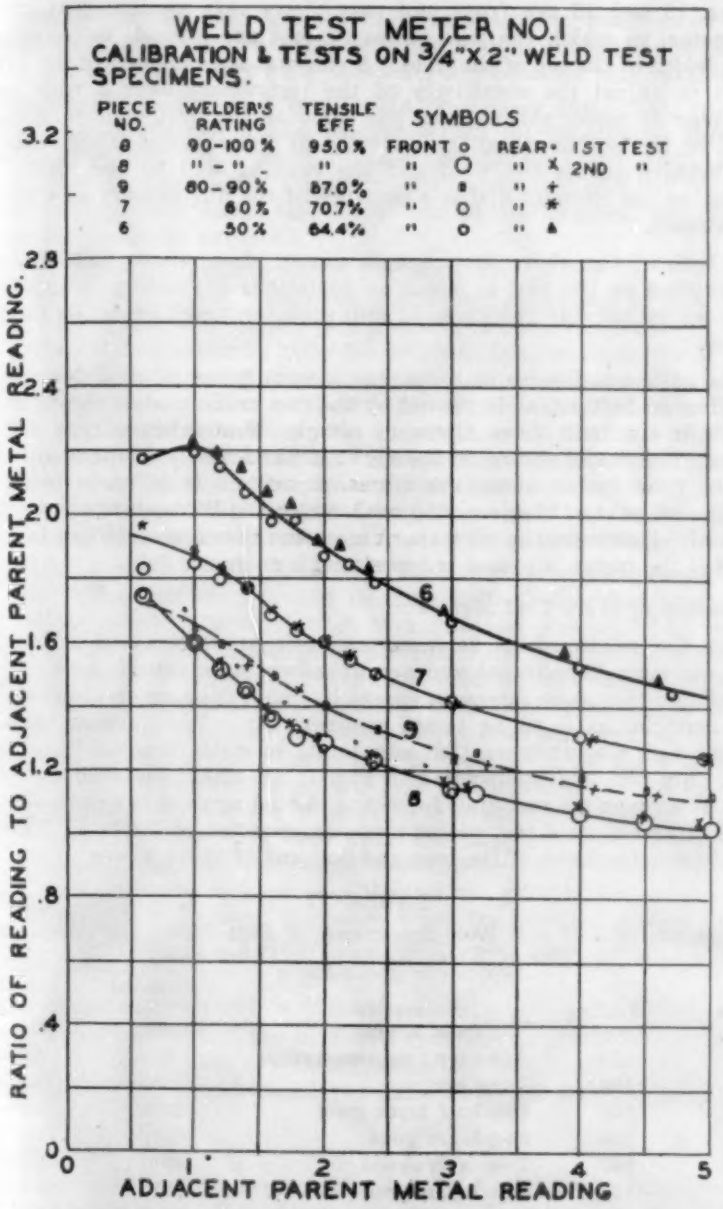


FIG. 17—CALIBRATION CURVES OF WELD TEST METER NO. 1. AT DIFFERENT MAGNETIZING FORCES OR FLUX DENSITIES INDICATED BY THE PARENT-METAL READINGS. CALIBRATION CURVES CAN BE PLOTTED AS WELD READINGS VS. PARENT-METAL READINGS IF PREFERRED

Figs. 12 and 13 are front and rear views of a similar type of weld test meter, in which the pole pieces or feet are hinged, to be adjusted to the width of the top of the weld. A rheostat is connected in the battery circuit to adjust the sensitivity of the instrument over a wide range. This type of meter can be used the same as the first one, or it can be placed on the parent metal and adjusted by the rheostat till it reads 1.0, then bridged across the weld and the reading will be the ratio. The reading on the rheostat dial is a measure of the flux density at which the test is made.

On both of the above instruments copper shoes about 0.020 in. thick are provided on the feet to minimize variations in readings which might be caused by varying thickness of mill scale, or rough spots, on the plate surface.

It is quite possible to make magnetic-vane types of weld test meters, requiring no battery, as is proved by the two crude models shown in Fig. 14, which are built from the very simple Westinghouse type BT ammeters. The model shown on the right is particularly adapted to finding lines of poor fusion along the edges of welds. It is made by simply grinding off part of the iron loop with which the BT meters are normally equipped. However, the permanent magnet in such meters can be easily ruined if the meter is placed in too strong a magnetic field.

Calibration of Weld Test Meters

Since the relationships between magnetic properties and strength of steels are very complicated and are unknown, no magnetic test can give any reliable clue as to strength, except by calibration on specimens of the same material as is to be tested magnetically. It is almost infallible, although not absolutely so, that any faults in welds increase their reluctance. This fact is demonstrated in Fig. 15, in which the weld test meter ratios at a given magnetizing force are plotted against per cent efficiency of weld, for ten weld test pieces made as specified in Table VI. Fig. 16 shows magnetographs of the tops and bottoms of these pieces.

TABLE VI

Specifications of 3/4" x 2" Weld Specimens. V Butt Welds. 30° Bevel on One Side of Weld; No Bevel on Other Side

Piece No.	Welding Amperes	Information from Welder	Estimated Per Cent Fusion	Actual Per Cent Efficiency*
1	150	Adhesion; no penetration	0	3.8%
2	150	Long arc	10%	10.2%
3	150	One-half layer good	20%	35.3%
4	160	One layer good	30%	41.1%
5	180	Two layers good	40%	58.2%
6	150	Two layers good	50%	64.4%
7	150	Two unfused zones	60%	70.7%
8	150	Four good layers	90–100%	95.0%
9	160	Four good layers	80–90%	67.0%
10	140	Four good layers	80–90%	59.6%

*Actual per cent efficiency is based on parent metal tensile strength of 50,650 p.s.i.

In Fig. 15 observe that the difference in magnetic readings of welds from about 70 per cent to 100 per cent efficiency is rather slight and uncertain, but that for poorer welds the difference becomes very conspicuous.

Magnetic and tensile test results are reasonably consistent, with the exception of Specimens 9 and 10, for which all predictions indicated better quality than was actually found in the tensile test. As the pieces were broken as welded, the straightness of the piece and the character of the reinforcement affect the tensile test results considerably, so that no precision could be expected.

Fig. 17 shows calibration curves for Weld Test Meter No. 1, made on Specimens 8, 9, 7 and 6, which the welder had estimated to rate 90-100 per cent, 80-90 per cent, 60 per cent and 50 per cent, respectively. These curves show the variation in ratio for different flux densities, the adjacent parent metal readings being approximately proportional to the applied magnetizing force. (The weld test meter may also be calibrated to measure flux density in a given kind of parent metal, but such calibration is not required for weld testing.) The different slope of the curve for Specimen No. 9 is the only magnetic indication of its inferiority. Greater reinforcement decreases the reluctance of the weld, of course, but in these specimens the reinforcements were as nearly equal as possible.

A group of more than a hundred V weld test pieces was tested by the weld test meter and then broken in the tensile testing machine. Each of these pieces was the best effort of a different welder. (All welders are required to submit a test piece periodically.) The pieces came from all departments of the plant using arc welding, and varied widely in amount of reinforcement, straightness and quality of workmanship, although the worst of the group was a 60 per cent weld and only 19 were poorer than 75 per cent in the tensile tests. Probably there were also differences in the composition of the bars and welding wires used, which may have made considerable differences in magnetic properties. Therefore, it was not surprising that when the magnetic tests were plotted against the tensile tests the points were rather badly scattered and did not definitely determine a curve, although the general shape of a curve like Fig. 15 was indicated. However, when the specimens were grouped by departments in which they were made, and each group considered separately, the results were much more consistent.

Effect of Residual Stresses on Magnetic Tests

Residual stresses affect the magnetic readings to a degree not yet fully ascertained. Indications are that tension has very little effect, but that compression tends to produce a lower ratio of reluctance of weld to parent metal.*

Conclusions

Weld testing by measurement of magnetic potentials is more quantitative and more nearly free from personal judgment than the magnetographic or other methods of inspection.

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*The effects of internal strains in magnetic materials are discussed by Mr. Thomas Spooner of the Westinghouse Research Laboratories, in his book on "Properties and Testing of Magnetic Materials." [5]

[5] Properties and Testing of Magnetic Materials—Spooner. McGraw-Hill Book Co. See "Internal Strains." Pp. 374-5, 1st edition.

Magnetic-weld test meters are small, rugged and usable in any position, and the results are easily and quickly interpreted by reference to calibration curves.

The method appears to be at least as practicable and reliable as any other non-destructive weld test method known, but precise predictions of strength are not to be expected, especially for welds of 75 per cent efficiency and better.

There are, of course, a number of undesirable features. It is rather difficult to get sufficient flux through structures of large sectional area, as cumbersome magnetizing means must be employed.

The instrument must be calibrated for the materials and type of weld to be tested, using a good weld as a standard, and drawing a curve of its weld readings vs. parent-metal readings at various flux densities.

No general definite relationship between strength and magnetic properties of steel is known, and slight differences in composition or heat treatment may alter the magnetic-properties greatly, without appreciable effect on the strength.

Residual stresses may distort the magnetic test results to an extent not definitely determinable.

The application of magnetic testing to other than butt welds does not give much promise of success, although very little work has been done on such applications.

Although little practical shop testing experience has been acquired, the laboratory investigations indicate that magnetic test methods at least detect any serious faults in welds, and give a more nearly accurate measure of weld quality than other known methods practicable for shop use, without requiring elaborate or delicate equipment or any high degree of skill and training.

Building Up Battered Ends of Rails*

W. H. KIRKBRIDE†

BATTERED rail ends have increased in the past years to such an extent that the subject is a topic of discussion among railroad maintenance engineers insofar as track maintenance is concerned.

Battered joints are caused by a combination of various factors such as increased tonnage and heavier power, variation in carbon content of rails, and difference in elevation of the top of adjacent rail ends. Joints which do not have sufficient gap to permit rail expansion, show the top edge of the ball is either upset or is chipped off, when the rail becomes tight. These chips and upsetting of the top surface usually start the end to batter. Regardless of the weight of the rail it is practically the same hardness on the surface. We have increased the weight of the rail to meet the requirements for heavier traffic and power but nothing has been provided to stop the flow of metal on the top surface of the rail, which occurs under the present heavy loads. The largest percentage of new laid rails show some difference in elevation of the top surface, from 0.016 inches to the limits of variations permitted in our rail specifications of 0.047 of an inch between an extreme low and high rail, causing the metal to flow from the high rail on to the low rail resulting in a chip which quickly develops into a battered joint.

The effects of the battering of rail in tracks especially those carrying high speed traffic are numerous and vary in their magnitude depending upon numerous factors.

In general these effects combine to result in increased maintenance cost due to the following: rough riding track and the necessity for larger expenditures for labor in surfacing and lining, increased wear on joint bars and rail at the fishing angles with consequent increased replacements, greater mechanical wear on joint ties and decreased life of tie, decreased life of rail in high speed tracks account of poor riding conditions of the rail.

The relative effect of these various items on maintenance costs varies with the traffic and other conditions which makes it difficult to predict.

The mechanical wear on joint ties under battered joints in some cases was noted to have reached an extent where 75 per cent of the average tie life had been destroyed. On a track where treated ties are used, this item represents a considerable loss.

Prior to the reconditioning of rail ends in track, one of the principal causes for removal of rail from high speed tracks, was the battered conditions of the ends which prevented the maintenance of the track in a safe condition for the required speed.

*Paper to be presented at Fall Meeting of the A. W. S., Chicago, September, 1930.
†Engineer of Maintenance of Way and Structures, Southern Pacific Co.

While definite conclusions cannot be reached as to an average increased cost due to battered rail ends, it is considered that in the maintenance of high speed tracks this cost amounts to a considerable item.

The above facts caused considerable concern with the Maintenance Engineers of the Southern Pacific Company. Realizing the seriousness of the battered joint condition which was developing at such an alarming rapidity, they immediately gave their utmost attention to employing a method to remedy the situation. There were two methods, cropping the rail, or welding the battered ends up by the welding process. Most all railroads at that time were familiar with the cropping of battered rail ends and this method proved satisfactory when rails did not batter so rapidly and the rail was permitted to remain in main line track until it had carried its full tonnage, then removed and relayed on branch

FIG. 1—BUILDING UP RAIL ENDS BY OXY-ACETYLENE WELDING

lines. However, conditions have changed and it would not be very economical to remove rail, of relatively short life in main line, crop it and relay it. The cropped rail when laid would also have the disadvantages of difference in elevation of the rail ends and would have 24 more joints per track mile to maintain.

The welding of battered joints in track under operation was started on the Southern Pacific Lines in 1913 and proved to be far more economical under the prevailing conditions than cropping the rail ends. This work continued with various experiments, and in 1918 and 1919, contracts were made to build up rail ends in main line tracks by Oxy-Acetylene Process.

This contract work was expensive and after an investigation it was decided to handle the welding with Company forces, using Oxy-Acetylene method. Gangs were organized and welders trained to build up rail ends by this method. By 1920, welding gangs were in operation on six of the Divisions. This organization was expanded so as to cover all Divisions and the organization continued to operate until 1928.

While the Oxy-Acetylene method repaired battered rail ends and lengthened the life of the rail in track, it was not an entirely satisfactory method.

This process necessitated the heating of the rail end and joint bars, resulting in bent bars. The metal deposited upon the rail contained less carbon than the rail, due to the oxidization of the carbon. Consequently the weld was softer than the rail and frequently battered more rapidly.

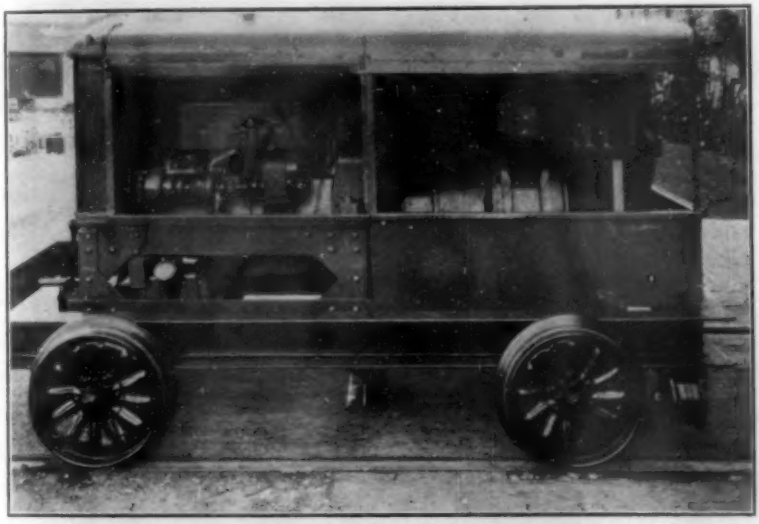

FIG. 2—VARIABLE VOLTAGE GENERATORS; FIRST MOUNTED ON FLANGED WHEELS IN 1926

The actual welding required an experienced welder who could properly apply the weld without burning the metal. It was necessary to train men to fill these requirements and some work of very little value was performed during the training of the first welders.

Experiments were begun in 1923 on the Pacific Lines in the building up of rail ends by means of the Electric Arc. A small portable outfit was constructed and a considerable amount was performed such as building up of manganese frogs, track crossings and rail ends in yards. These experiments were so successful that a second machine was constructed in the Company's shop.

The first work of this machine in building up rail ends in main line tracks was performed in 1925. At this time adequate grinders had not been developed and the joint gaps were cut out with a hack saw and beveled with a file. These joints consequently did not have the finished appearance which is now obtained, however, these particular welds were never rewelded and permitted the 90 lb. rail to remain, in track until April, 1930.

The successful results obtained from these first two machines in

main line welding, resulted in the building of two machines which were suitably designed for main line work. The electric welding organization was increased by substituting this method and the electric machine in the welding gangs, supplanting the Oxy-Acetylene method.

The Oxy-Acetylene equipment continued in use, but was restricted to yards and to scattered jobs. The increase in the use of welded signal bonds now necessitated this equipment in the signal gangs.

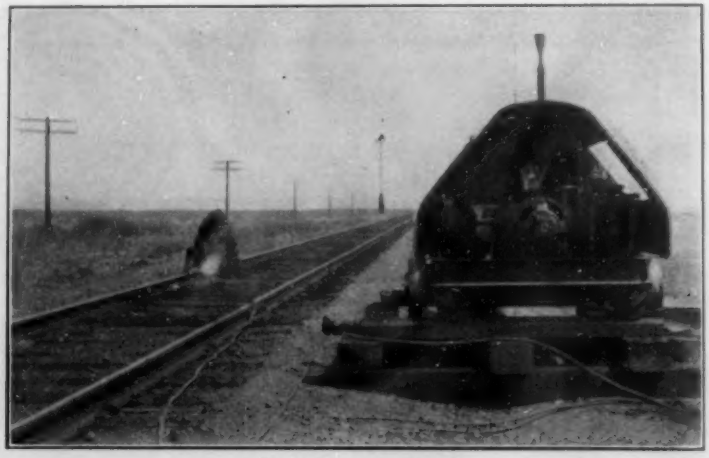

FIG. 3—WELDER AT WORK

The development of the Electric Arc method has eliminated practically all of the troubles encountered in the Oxy-Acetylene method. The rail and joint bars are not heated and a long experience is not required in order to train welders.

Direct current is used for welding with high carbon welding rods, which deposits material with a similar carbon content as the original rail. Rail ends built-up with this process have held up under heavy traffic as well as new rail.

At present the Pacific Lines have 21 Electric Arc Machines in operation and while the later built equipment is more efficiently designed than the first machines, they are all giving excellent service.

The following instructions govern the building up of rail ends by the Oxy-Acetylene and Arc Process on the Southern Pacific Lines.

1. Rail in primary main tracks will be conditioned by building up the rail ends with the direct current electric arc process. The oxy-acetylene process may be used for small scattered jobs including repairs of frogs and turnout material in yards, etc., however, the Arc Process will be used even on scattered jobs whenever it is more economical. For the repair of manganese material only the Arc Process will be used.

2. Battered rail in other tracks will be conditioned in a similar manner.

The extent of welding on such tracks will be limited depending upon the amount and character of the traffic over such tracks.

3. Batter:

Rail batter is the distance in 64ths, or in thousandths of an inch, between the bottom of a straight edge 24 in. long, applied along the center line of the worn surface on the top of the rail (with one end coinciding with the end of the rail) and the top of the rail measured at a point ½ in. from the end of the rail.

4. Welders will measure the batter of the rail end, and welding will be limited to joints where the rail ends show on one side or the other of the joint, a batter of 3/64 (0.047) in., or more; or where excessive chipping has occurred.

FIG. 4—NARROW GRINDING WHEEL USED TO BEVEL THE RAIL ENDS AFTER WELDING, TAKING THE PLACE OF FILES WHICH WERE PREVIOUSLY USED

The build up of batter should not be resorted to until a batter of at least 3/64 in. is found to exist.

5. Where receiving ends of rails are cupped and the surface upset, the cupped surface will be built up when its depth under the straight edge is 3/64 (0.047) in. or more. The upset portion of the rail surface will be ground off.

6. Where rail ends are not battered to an extent requiring welding but where measurement shows a difference in the height of the rail of 3/64 (0.047) in. or more, the high rail will be ground down to the height of the low rail.

7. In the territory covered by the Electric Welding Machines, all metal fins at the joints will be ground out, regardless of whether joint is welded or not and the rail ends beveled.

8. The results obtained through the building up of rail ends depends not only upon proper welding, but also upon proper track maintenance.

Track forces will handle the following maintenance work directly in advance of the welding.

(a) Close up excess expansion at the joints and apply or adjust rail anti-creepers.

(b) Apply new angle bars if necessary, with standard heat treated bolts. Where angle bars are only slightly worn, remove and reverse bars. Apply oil to the fishing angles of all angle bars and rail and tighten all bolts.

(c) Renew joint ties if necessary.

(d) Remove unclean ballast at the joints and replace with clean ballast from adjacent section of the roadbed.

(e) Tamp up ties and surface and line track.

(f) Previous to welding, all joints must be ground out with portable electric grinder, grinding away all possible laminated metal, oxidized metal and other corrosions which result in improper fusion of the parent metal and rod.

In addition to the main line welding, several of the machines, especially those in Oakland, have been used extensively in the work of elimination of rail joints in paved track by seam welding of the joints and in the repairs of frogs and track crossings.

Two different types of Arc Welding Machines are being used on Southern Pacific Lines; the variable voltage arc welding generator and the constant potential welding generator. Each one has its advantages and is used where best adapted. All the welding generators used in the Maintenance of Way Department are gas engine driven. The first seven sets purchased were the variable voltage type, 60/20 volts—self regulated. These machines were 200 and 250 amperes capacity, each unit was equipped with 220 volt D. C. auxiliary generators of 3 kw. capacity used for operating the electric track grinder. The first of these seven machines was mounted on a trailer and has been in constant operation for over seven years. However, the gas engine was renewed two years ago but we expect to obtain several more years' service from the machine before discarding it. The next two generators purchased were mounted on tractors, both are in excellent condition and are performing very satisfactory work in yards. The other four variable voltage generators and gas engines were mounted on steel frames with flanged wheels for main line work building up battered joints, these units would cover only 1000 ft. of track at one move or setting up or 500 ft. each side of the machine, 4/0 rubber covered cable was required to carry the current. Cable smaller than 4/0 would not carry sufficient current to maintain the proper arc for satisfactory welding due to voltage drop.

We were very well satisfied with the operation of this equipment on main line track up to 1927, when we conceived the idea that the constant potential generator was preferable for the building up of battered rail ends on main line, and we designed a machine to suit our requirements which was built in San Francisco by well known manufacturers of electrical equipment. A total of eleven double operator and two single operator machines has been built to date by the manufacturer for the Southern Pacific Company.

The double operator units consist of a 75 hp. 6 cylinder gas engine

driving two 60-volt, 275-ampere direct current constant potential generators, coupled in tandem with flexible couplings, each generator being insulated from the other and the frame. This insulation is necessary to avoid interference with block signals and welders are permitted to work on either rail regardless of which rail the opposite welder is working on.

The engine, two generators and resistance grids are mounted on steel frame with flanged wheels and small roller wheels for removing from track. The over-all dimension is 12 ft. long and machine weighs 5500 lb. and is moved as easily as the smaller machine. The average time required for moving 3000 ft. is 15 min. Other advantages of the constant potential generator machine over the variable voltage machine are: it will cover 2000 ft. more track at one moving with much smaller cable, each welder

FIG. 5—TRACK GRINDER DEVELOPED IN THE FIELD BY WELDING FORCES TO TAKE THE PLACE OF SMALL HAND GRINDER

and grinder operates from the same ground or return cable. This return cable is 4/0 round copper bare cable 1500 ft. in length, the volt drop of the cable when working 1500 ft. from the generator is 17.5 volts, assuming the current is 225 amperes, the opposite cable is rubber covered flexible cable consisting of 500 ft. of 2/0 and 1000 ft. of number one. The combined volt drop of this line when working is 36.5 volts, making a total drop of 54 volts.

The generator is slightly compound and the governor is designed to speed up the engine enough to obtain the necessary voltage to properly weld, or 75 volts at the generator. Each generator is supplied with stationary cast iron grids for resistance, these grids are used as the welder gradually works closer to the machine. Another advantage is the track grinder operates from the welding generator.

The motors on the track grinders are specially wound for 50 volts and about 30 amps. Using the same 4/0 return cable that the welder used we have a drop of 2.2 volts, assuming the welder is not welding the other grinder line consists of 500 ft. of No. 2 rubber covered cable

and 1000 ft. of No. 4 rubber covered cable a combined drop of 10 volts and a total drop on both lines of about 12 volts.

When the welder is not welding the voltage is 60 or 65 volts at the generator and the instant he strikes the arc the generator builds up to 75 or 80 volts which compensates for the drop in the 4/0 cable. With this arrangement an even voltage is obtained at the track grinder motor and very little trouble has been experienced with the motors.

Shortly after the constant potential type were started operating and proved much more satisfactory for rail welding on main line, the variable

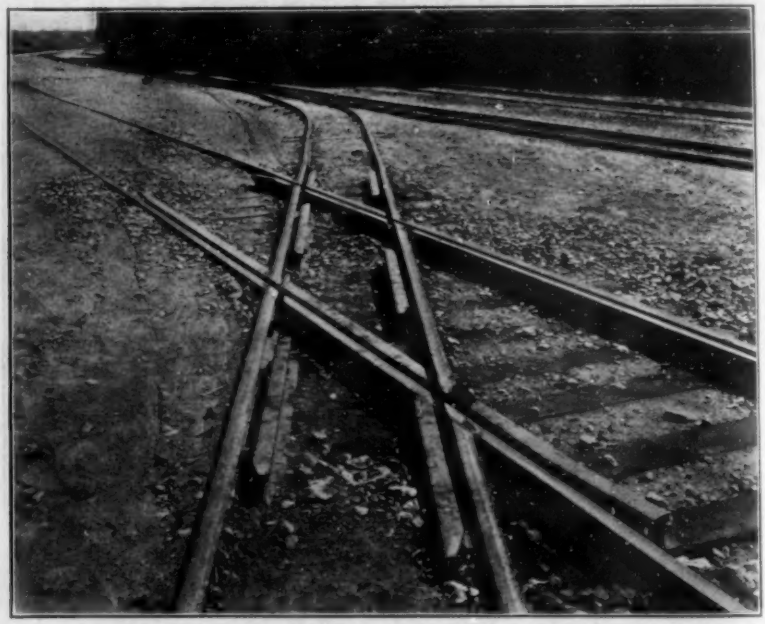

FIG. 6—CROSSING BUILT BY ELECTRIC WELDERS IN THE FIELD

voltage machines were mounted on 1½-ton trucks for use around terminals and city streets. This class of equipment has proved itself so valuable in various kinds of other than track work, such as tank welding and making other repairs coming under the supervision of the Maintenance of Way Department that another additional 300 amps. variable voltage gas engine set mounted on a 1½-ton truck was recently purchased.

In 1925 when the electric welding of battered joints was started on main line the only means of grinding the surface of the rail after the weld was applied was a hand grinder. This method involved far too much time and, in view of the fact, that no track grinders suitable for operation on high speed steam lines were available, it was necessary to design and build one for our necessities. This was done in the field shortly after starting with our second machine in 1925. It was a 2 hp. motor clamped in a carriage mounted on a frame constructed of common

pipe with all joints welded, having flanged wheels. We have made a few improvements such as using seamless tubing, instead of pipe, which lessen the weight and have installed roller bearing flanged wheels in place of the common guide wheels. However, it is practically the same as the first one built. It performs excellent work and only weighs about 200 lb., including motor.

We have done considerable experimenting and testing by actual service under traffic load with various welding rods. For gas welding of carbon rail ends we specify a nickel rod, however, we are obtaining very good results from high carbon rod and are arranging to revise our specifications from nickel to high carbon rod for oxy-acetylene welding. For electric-arc welding of rail ends we use nothing but high carbon coated rods. Our specification for this rod is 0.90 to 1.10 carbon and about 0.60 manganese. From past experience we find the results from high carbon rod much superior than any other rod with lower contents of carbon and substituting alloys. Much better fusion of metal is obtained from rod meeting our specifications, due to the fact that the metal deposited from high carbon rod and the parent metal of the rail are almost identical. For manganese casting we specify rod containing 12 to 14 per cent manganese and coated.

Inspections have indicated that the battered joint properly welded by the electric-arc process and using 0.90 to 1.10 carbon coated welding rods, do not batter as rapidly as the original rail, due to the higher carbon contents of the rod.

In building up of rail ends either by the oxy-acetylene or the electric-arc process, the costs include all labor and material, tools, grinding wheels, etc., used in the welding, also all the cost for repairs and repair parts.

The total number of joints built up by the oxy-acetylene process up to January, 1930, was 669,511 joints, at an average cost of $1.21 per joint.

The number of joints built up by the electric-arc process up to July 1, 1930, was 541,369 joints, at an average of 66c. per joint, which includes interest and depreciation of equipment.

The personnel of our Maintenance of Way welding organization consist of, one system supervisor. Each double operator gang consists of, one lead welder whose duties are similar to a foreman, 2 welders, 2 grinder operators and 3 helpers. The single operator gangs consist of 1 welder, 1 grinder and two helpers.

We have found that the plan of arc welding battered rail ends on the Pacific Lines of Southern Pacific has brought about a much smoother riding track, economies in the expenditure of labor for track maintenance and the conservation of material used in the track structure.

The results have been so manifest that the management of our company has granted authority to purchase the additional machinery that will fully equip us for keeping up with the development of all batter in track before objectionable conditions exist.

Resistance Welding of Steel Joists*

By Frank Burton†

WE are all familiar with the old fashioned smith's weld made by heating two pieces of low carbon iron to about 2150 deg. Fahr. and joining them by pressure from hammer blows. When such welds were properly made and all slag and iron oxide were removed from between the two pieces of metal they were very reliable. Usually, however, this was not the case. Often welds were made at too low a temperature and there was insufficient heat and pressure to exude impurities trapped between the welding surfaces. Also since control of carbon content was unknown it frequently happened that the iron "burned" while being heated and was found to be seriously weakened as a consequence if it did not actually crumble under the hammer. We know now that the "burning" of iron (or rather steel) is due to the growth of large crystals followed by the formation of an oxide film between the grains which is a characteristic of steels having carbon contents of between 0.4 and 0.8 per cent when heated to about 2500 deg. Fahr. In consequence of these difficulties smith's welds especially when made with other than very pure iron were always looked upon with suspicion.

Since the development of modern welding methods a great deal of work has been done upon electrical resistance welds which appear in many ways to be identical with smith's welds and since very little literature has been published upon the subject many engineers are inclined to attach to these welds the same suspicions they hold for smith's welds.

A careful study of the subject, however, reveals several important differences between the two methods and indicates that resistance welds made with proper machines are extremely reliable and of uniform strength.

The subject has been treated so inadequately in all the literature which the speaker has been able to find that you must pardon him for approaching the matter in a rather elementary manner.

It has long been known that passing a large electric current through two pieces of iron in contact will cause the junction to heat. If pressure is applied, the surfaces may join, forming a weld. This is simple enough but we must now determine the necessary and sufficient conditions to produce a sound and reliable weld.

Experience shows that if the metals are held loosely the rough surfaces, covered with a layer of scale, will be heated very unevenly. Metal will be fused and even volatilized, also the surface will oxidize and little or no pure solid metal will be found at the junction. If on the other hand the pressure between the faces of the metal is too great the metal will be badly distorted and often greatly weakened. In welding thin

*Paper to be presented at Fall Meeting of the A. W. S., Chicago, September, 1930

†Consulting Engineer, Detroit.

sheets of metal the electrodes may be forced into the soft hot iron, rendering the sheet very thin at the point where the weld is formed. Although the weld may be sound, the area of metal around the weld will be insufficient to develop the strength of the weld.

If the current density is low the entire mass of metal between the electrodes will be slowly and quite uniformly heated. This is wasteful of current and if the carbon content is high there will be considerable growth of grain and possibly burning. Also the metal will be excessively distorted by the pressure necessary to produce a good weld. Too high a current density will result in undesirable and excessive temperatures and may cause burning.

It does not appear, however, that we can place any exact limits upon the pressures and current densities desirable for this purpose at this time because of the wide variation in practice in various shops all of which are producing good welds. We may, however, say in a general way that there should be from 200 to 300 kilowatts of current available for each square inch of surface to be welded and that the pressure should be between 8000 and 10,000 lb. per sq. in. of weld. With these two conditions established the remaining factor, time, may be varied to obtain satisfactory welds. The time will usually be found to be between 1/5 second and 1½ seconds.

A single phase alternating current is used and it is transformed from the line voltage to from 5 to 14 volts on open circuit. When the circuit is closed about one-half of the total energy is dissipated in iron and copper losses in the transformer. The resulting secondary current is from 20,000 to 40,000 amperes per square inch of welding area. The heat rise is very rapid but by no means uniform.

From a study of some typical examples of welds made in steel joists it appears that the resistance of the cold steel between the electrodes is far from sufficient to hold back the current flow. If the surfaces to be welded were in perfect contact the secondary coil of the transformer would be effectively short-circuited and almost all of the energy would be consumed in iron and copper losses with excessive current flow in the primary. As a matter of fact the steel always has a slight coating of rust which offers a relatively high resistance. A heavy coating of rust will prevent the flow of current and there will be no weld. A coating of about one to two thousands of an inch thick will furnish just about the resistance necessary to permit the desired current to flow and will develop 80 or more per cent of the total heat in the rust film during the first few hundredths of a second. This results in melting the iron oxide to a liquid which is forced out from between the surface to be welded, partly by the mechanical pressure and partly by the magnetic field of the secondary circuit. By this time the metal of the point of contact has attained a high temperature which results in a resistance about 10 times that of cold iron. The heat produced is proportional to the product of the square of the current times the resistance, consequently the very hot metal at the contact rises in temperatures much more rapidly than the cold metal further from the junction. The metal at the point of contact becomes plastic or even fused by the time the metal ⅛ of an inch away has attained a red heat.

Just before the current is applied the pieces to be welded are forced together with a pressure of about 2000 lb. per sq. in. and this is quickly raised to from 8000 to 10,000 lb. per sq. in. after the current is applied. The result is a perfect fusion of metal at the junction which is free from slag or oxide (also from nitrides) without any appreciable distortion of the metal more than about 1/16 of an inch from the junction. Within the space of about 1/16 in. or less from the junction the metal will have flowed quite freely forming a perfect joint with a little excess of metal extruded around the edges.

The machines used for resistance welding are so variable in character that no detailed description is possible. For any given piece of work a machine must be designed to suit the especial needs. The general feature common to all these machines is a heavy single phase transformer so wired that the secondary potential can be varied from about 5 to 14 volts by adjustments to the primary circuit. The transformer must be built into the welding machine as the secondary leads must have areas of from 10 to 20 sq. in. of copper. Pressure is applied by means of a suitable cam geared to the current controlling mechanism and an adjustable rotating circuit breaker is provided on the primary circuit.

The making and breaking at frequent intervals of such large current circuits as are required in this work places a very heavy burden upon the generating station. If a station of large capacity is available the inequalities in current demand can be absorbed but if a small generator is to be used it must be provided with an ample fly wheel. Even with current from a large power station it is necessary to provide ample capacity across the lines to absorb the line surge.

The shape of the pieces to be welded is of great importance. The welding of thin sheets is possible by using a blunt pointed copper electrode forced against the sheets with sufficient pressure to insure contact opposite to the electrode but there is always a certain indentation into the sheet that reduces the strength of the sheet around the weld. Often this becomes considerably less than the strength of the weld and such welds when tested are found to fail by tearing away from one of the sheets, leaving a solid button of metal attached to the other sheet.

The plain butt weld is the ideal resistance weld. The bars to be welded are tightly gripped in copper electrodes near the ends to be welded and pressed together. The current is then applied and the bars made to approach each other about 1/16 in. for bars of ½ and 1 sq. in. in area and lesser distances for smaller bars. Considerably lower current densities may be used in this work but at a sacrifice of time. The weld is practically perfect with only a slight bur at the joint. The strength of such welds in tension is 93 or more per cent of the strength of the original bar.

In making open web steel joists the parts to be joined are the chord section and the web member. Two different types of joist are now in production using this welding process.

In one case (Fig. 1) the chord section is a blunt T shaped section having a width at the base of the T of ⅜ of an inch. The web is a round

bar bent over a pin of ½ in. radius. The web bars vary from 7/16 in. to ¾ in. in size. The joist is assembled with the web in a horizontal plane and the current is applied to the chord section by a large flat copper electrode. The web member is forced against the base of the T by means of a copper electrode shaped to fit the inner curve of the web member. Pressure is applied by means of a cam. By bringing a doubly curved surface against a flat surface the original contact area is very small and the line of flow of current is very definitely fixed. Fusion occurs quickly at the junction and the advance of the web mem-

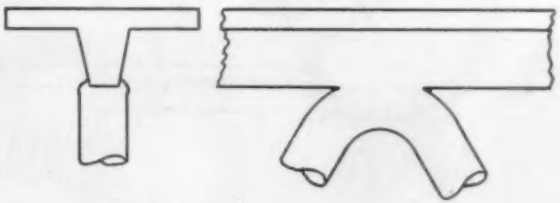

FIGURE 1.

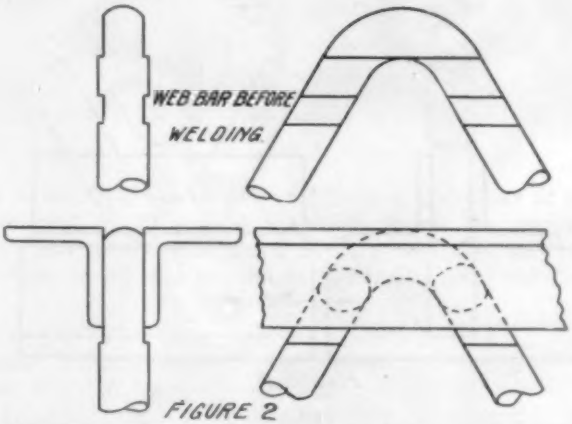

FIGURE 2

ber results in a flattening of the web bar at point of contact. All slag and oxide are forced outward and the resulting weld is invariably sound. The area of the weld is from 1¼ to 1¾ times the area of the web bar.

In the other type of joist (Fig. 2) the top chord consists of two small angles ⅛ to 3/16 in. thick with legs of 1¼ to 2 in. The web bars are 7/16 in. to 11/16 in. round bent around a pin of about ½ in. radius. The joist is assembled with the web in a horizontal plane and current and pressure are applied with flat copper electrode to the two angles, the web member being placed between the angles.

The area of contact would be so large that transformers of very large

capacity would be required if all of the web were exposed to the angles and the resulting weld would be unnecessarily large. To avoid this the web member is placed in a press and all parts of the web coming between the angles are flattened about ⅛ in. except for two lugs about ½ in. long near the center of gravity of the angles. These lugs are permitted to project to their original height thereby concentrating the current on two singly curved surfaces about ½ in. long. The resultant weld is a pair of disks of almost the exact diameter of the web member. The

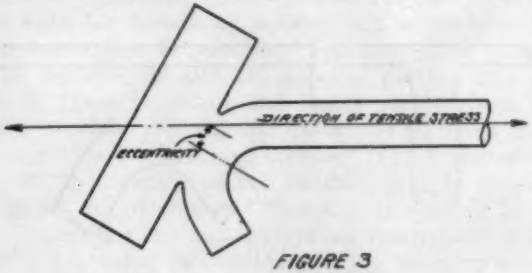

FIGURE 3

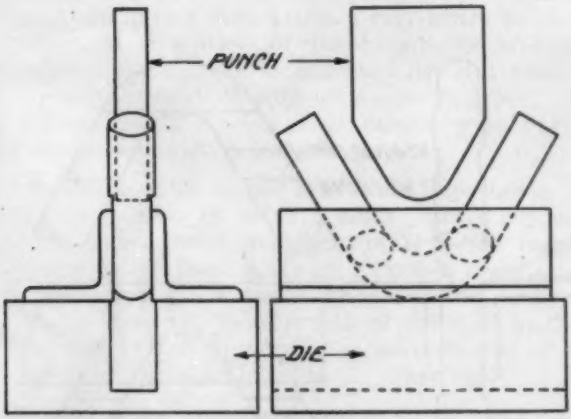

FIGURE 4.

control of current flow is not so exact as in the first case but the welds are considerably larger since there are in all four welds at each joint having a combined area of four times the cross-section area of the bar.

In this operation four welds are made at once, there being two welds in series on each of two parallel circuits. It might be thought that the welds would be unequal in size but this does not appear to be so. Each pair of welds in series receives the same amount of current and the two parallel circuits appear to distribute the current equally. This is no doubt due to the rapid increase of resistance of iron with rising temperatures which automatically reduces the current flow through either path that receives more than its share of current since the temperature and consequently the resistance will rise rapidly in the favored circuit.

It is essential, however, that the composition of the two pairs of angles should be quite similar and that the coating of rust should be even and uniform to insure satisfactory results.

It is difficult to determine accurately the strength of the weld metal in welds of steel joists for the reason that these joints are designed to resist shearing stresses and are usually so large in proportion to the bars connected that the connected members pass their elastic limit long before the weld fails. The weld then acts as a notched section and no accurate analysis of the stresses is possible. Accurate information may, however, be derived from a study of butt welds.

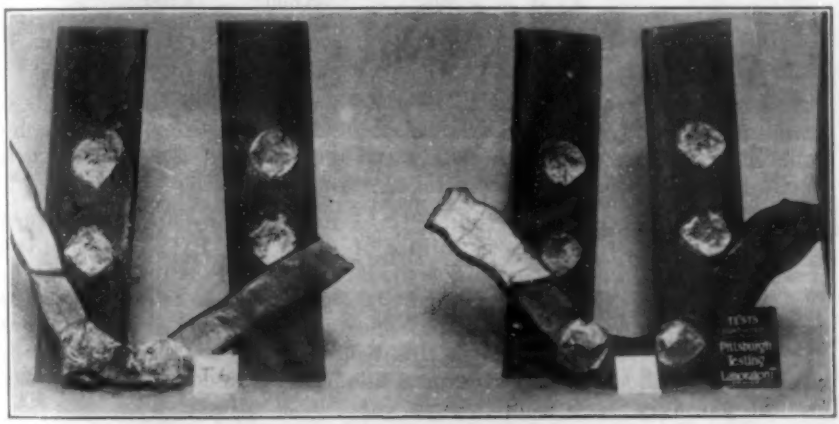

FIG. 5

Standard tensile test pieces were cut from a ¾-in. bar of steel containing 0.15 per cent C. The first specimen shows the properties of the original bar, the second and third contain welds in the center of the reduced portion, which was ground to ½-in. dia. after butt welding.

No.		Yield Point	Ultimate	Elongation 2 In.	Reduction of Area
1	Unwelded	36,990#/□"	59,190#/□"	35%	42%
2	Welded	37,760	58,930	30%	20%
3	Welded	38,010	58,680	35%	42%

Both samples failed outside of weld but sample 2 shows the effect of heating the bar adjacent to the weld. These results are typical for well-made butt welds in low carbon steel. They indicate that the strength of the weld is substantially the same as that of the original metal but that the properties of the metal are somewhat affected by the heat of the weld.

Some tests have been made upon joints of steel joists of the type first described above (see Fig. 3). The flanges of the chord section were cut away to permit gripping in test machine and tension was applied to one of the diagonals. The weld is an ellipse and when tested in this manner is subject to both tension and shear. The web bar having been bent around a ½-in. pin is slightly curved adjacent to the weld, with the

result that the center of the tensile stress is eccentric with regard to the weld. By calculating this eccentricity and determining the area and amount of inertia of the elliptical weld it is possible to determine the maximum fiber stress in the weld area due to direct tension and bending. The sum obtained by adding the unit stress due to the tensile component and the maximum fiber stress resulting from bending is given as maximum tensile stress. Each result is the average of four separate tests.

Chord Section	Web Bar	Average Load at Failure	Area of of Weld	Max. Tensile Stress in Weld	Unit Shear in Weld	Unit Tension in Web Bar
400	7/16 Rd.	7,160#	.260□"	64,200	13,450	47,600
401	1/2	8,770	.298	65,600	14,700	44,750
401	9/16	11,645	.343	73,200	17,000	47,200
403	5/8	13,440	.392	70,500	17,200	43,900
404	3/4	16,210	.515	64,200	15,700	36,700

These results cannot be taken as strictly accurate, as there is considerable uncertainty as to the exact areas and eccentricities, but they undoubtedly approach the truth closely and indicate that the weld metal is sound, low carbon (about 0.18) steel of normal properties.

All attempts to test the second type of joist weld by applying tension to the web members results in failure of the webs. By placing the two chord angles flat on a slotted die resting on the bed of a testing machine and applying pressure by means of a steel punch cut to fit into the curve of the web member it has been possible to punch out these welds (See Fig. 4). The stress produced in this test is nearly a true shear but is, of course, complicated by friction and distortion of metal. The following are the averages of 5 tests in each case.

Size of Chord Angles	Web Bar	Load	Approximate Area of 4 Welds	Ultimate Shearing Value of Weld, Pounds per Sq. In.
2 x 1¼ x 3/16	5/8"	43,911#	1.2□"	36,600
1¼ x 1¼ x 3/16	5/8	49,546	1.2	41,300
2 x1¼ x 3/16	3/4	59,396	1.76	33,700
1¼ x 1¼ x 1/8	1/2	37,752	.8	47,200
1¼ x 1¼ x 3/16	1/2	44,355	.8	55,400
1¼ x 1¼ x 1/8	5/8	40,360	1.2	33,600

In the last test the area of the metal in the angles around the welds is only 0.98 sq. in., or less than the area of the welds. Based upon this area the unit stress was 41,000 lb. per sq. in. The area of these welds is rather uncertain and consequently the results are quite variable. Failure occurred in each case by shearing of the two welds on one side of the web member. Naturally the two welds which were smaller would fail in each case, giving results corresponding to an area somewhat less than the average. We have very little data as to what value we should expect as an ultimate shearing value but tortion tests of low carbon steel give values of about 46,000 lb. sq. in., which check reasonably with the values above considering the great uncertainty of the actual weld area. The photographs Figure 5 are of two test pieces of the second set in above table.

The procedure in making resistance welds, excepting those in thin sheets, is about as follows: The parts to be welded are so designed that

the current flow will be at right angles to the electrodes, permitting pressure to be applied to the electrodes during heating. The area of metal in contact with electrodes must be large and the area of metal between electrodes and point where weld is to be formed must be larger than area of weld. The area of the original contact point of the two members to be welded must be quite small to concentrate the current and localize the initial heating. The increase of resistance in the hot metal will insure the continued localization of heat when once started.

Knowing the character of the weld desired, the necessary pressure is estimated from previous experience. The primary of the transformer is now adjusted to give from 200 to 250 kw. per sq. in. of weld and the time adjustment arbitrarily set at about one second. One or more test welds are made and broken open with a sledge hammer. If there is insufficient fusion of metal, the time must be increased; but if this results in undue distortion of the members, the time must be reduced and the current increased. A number of trials must be made, varying first one and then another of the three variables until satisfactory welds are obtained. The transformer setting, pressure and time are then recorded as suitable for that particular weld and these adjustments will hold good as long as there is no material variation of the steel used and the condition of the surface of the metal is fairly constant.

It is neither necessary nor desirable that the surface of the metal should be perfectly clean. Sheets of steel which have been freed from all rust by pickling in acids cannot be welded by this process. A slight coating of rust or other foreign matter appears to be essential to the process as it causes a pronounced localizing of heat at the point of contact. The metal must not be badly rusted or scaled but should have a thin, uniform coating of rust such as is normally present on commercial bar stock.

With an automatic machine having all variables determined, the personal error is entirely removed and all welds made by such a process should be uniform, provided the condition of the surfaces are uniform. Experience proves that this is the case to a much greater degree than in any other type of welding.

As to the effect of chemical composition, if we consider only open hearth carbon steels we may, for the present, dismiss consideration of sulphur, phosphorous and silicon because they are all present only in small quantities and the amount present is fairly uniform. It is quite possible that further studies may prove that sulphur is an objectionable impurity, but it is quite certain that very good welds can be made with steel containing 0.05 to 0.06 per cent sulphur, and it is scarcely necessary to consider steels with higher sulphur contents.

The carbon content of most steel used in this process is about 0.18 per cent and until recently it was considered unsafe to attempt resistance welds with steel having over 0.25 per cent carbon. This opinion is no doubt due to the difficulties encountered in making smith welds in high carbon steels. Recent tests indicate, however, that sound and reliable butt welds may be made in steels up to 0.65 per cent carbon and that such welds will develop a strength equal to the strength

of the original bar. Up to a content of 0.45 the test piece showed a good ductility with most of the failures outside of weld but above 0.50 carbon there is a tendency for the bar to break in the weld with only slight elongation, but at a load equal to that required to break an unwelded test piece. There is evidence of a slight hardening of the metal near the weld but no indication of "burning." This may seem rather remarkable considering experience with smith's welds but the explanation is quite simple. When a fairly high carbon steel is heated above 2400 deg. Fahr., the grain size increases rapidly and there is a tendency on the part of the metal between the grains to oxidize, causing the large grains to separate and resulting in a loose granular "burned" metal. Of course it is not necessary to heat to 2400 deg. Fahr. to weld but it is difficult to control temperatures in a forge and the metal must be somewhat overheated in order that it will remain at or above the welding temperature while the weld is being forged. In a properly made resistance weld there should be no burning, first because the metal is under pressure and is consequently being worked as soon as it passes about 2100 to 2200 deg. Fahr., where it becomes plastic. Grain growth does not take place in metal being worked. Second, there is no occasion for overheating since the pressure is applied before the metal is heated and the metal flows increasing the weld area and decreasing the heating effect as soon as it reaches the beginning of the plastic range. Dangerous burning will take place in resistance welding if pressure is not applied before the current is turned on or if the current is left on after the metal has yielded sufficiently to release the applied pressure. It is true that in flash welding the current is turned on before the two pieces of metal to be welded are in contact. In this process, however, rather lower current densities are used and great care must be taken not to permit the arc to run for more than an extremely brief period before the two metals are brought in contact. Unless the greatest skill is used in this process burns are quite common.

The quantity of manganese present in steel undoubtedly has a considerable influence on the character of the weld, but at the present time there is insufficient data to justify any definite statements. It appears that manganese content of 0.40 to 0.60 is satisfactory for steel carbon content 0.15 to 0.25 and that this amount of manganese is preferable to smaller amounts. For the present it would seem advisable to concentrate attention on maintaining the manganese as constant as possible.

Not many studies have been made as to the metallographic properties of the metal in resistance welds. There appears to be no reason to fear that the character of the metal will not be satisfactory, since it has been found as a result of analysis that there is no chemical change whatever in the weld metal. Analysis of the weld metal checks exactly with the metal of the pieces from which it is made. Speaking particularly of steel joists, we know that the hot rolled bar stock, if finished at a temperature not much above the critical range, will be a fairly fine grained sorbite. In making a resistance weld the metal at the junction and for a little distance each side will have been heated past the critical range very quickly and cooled fairly quickly. The heating will tend to refine the grain, but the time of heating is not sufficient to permit complete

absorption of the cementite present in the sorbite, so that the original structure will not be entirely destroyed. If the pieces to be welded are so designed that there is a very large mass of cold metal adjacent to the weld it might be that some martensite or more probably some troostite might be left in the weld, but all commercial welds that the speaker has seen remain at a good, red heat for ten to twenty seconds after the weld is complete, which should be sufficient to destroy all martensite and probably all troostite in low carbon steel free from important quantities of manganese and nickel. We should expect therefore to find the weld metal to be a fine grained sorbite in low carbon (under 0.45) steels and in steels of higher carbon content we might reasonably expect to find a small amount of poorly developed troostite at the center of the weld. The behavior of the welds in high carbon bars (over 0.50), which were mentioned previously, is in accordance with these conjectures, since brittleness is evident in the welds when the carbon content passes 0.50 per cent.

In some published microphotographs of resistance welds it was observed that the microstructure of the weld differed very little from the remainder of the metal but the structure appeared much darker. The author attributed this to a higher carbon content, which is quite impossible since there is no source from which the extra carbon could be obtained. The carbon content and method of etching were not given but the speaker's interpretation of the darker structure is that it was due to a small amount of troostite, which always etches to a darker color than sorbite. The presence of troostite is in accordance with expectations and explains the greater hardness of weld metal over the original stock but it is quite possible that the structure of the troostite is too poorly developed to recognize.

In closing it is pertinent to call your attention to the fact that resistance welding is rapidly becoming of prime importance as a method of shop fabrication. Large current sources and expensive machinery are necessary for successful operation, making it impossible for the individual experimenter to study this method in the same way that arc and gas welding have been studied. In the shops of large organizations it is, however, proving a most reliable and economical method of welding which is destined, in the speaker's opinion, to eventually take rank as the welding method of first importance in shop work.

The Possibility and Further Development of Railway Welding*

G. W. LIEBER†

THROUGHOUT the many years of human existence there has been a constant advancement in the development of economical practices applied to that present day method of operation. History relates to a great extent the advancement and progress during every age, but not

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in any detail of the various methods applied to further the advancement of economical practices. From generation to generation we became better educated to the necessity of bringing to the attention of the public difficult problems confronted, and the possibilities offered in devising ways and means of overcoming these obstacles that prevented further advancement of economical operations. As the human element became more practical, especially in the mechanical field with the aid of a better education, new methods and practices were developed that today we stand foremost in the development of practical and economical methods of carrying on the operation of our various industries.

Throughout the past century there has been a steady increase in the operations of American railroads, brought about by the constant study of men, who well understood the problem confronted in working out a network of railroad systems to care for the constant increasing demand and the rapid development of this vast area. The establishment of a railroad system was somewhat a problem in itself, a greater problem confronted the railroad builders, after the net work of systems had been planned, consisting of the transporting of freight and passenger traffic. This brought far more study than the laying out of a system of rails from the fact that the roadbed at that time was of such construction that it required the mind of a genius to develop a locomotive and car that would follow the roadbed with a degree of safety and rapidity. To this end wonderful improvements were made in new designs, new devices to our rolling stock, together with improvements through engineering study in development of roadbeds. With the addition of new devices and improvements to our locomotives and cars, they naturally increased the cost of maintenance, likewise increasing capital investments, which no doubt was balanced by increase in revenue. The rapid development of improved devices, for more economical operations, especially in the past 25 years, has been so great that the increase of revenue on many railroads was not sufficient to offset the difference. Therefore the addition of new developments, increase in maintenance cost, coupled with increased wages, has brought about the establishment of a new department of the railroads, materially assisting in the reduction of operating cost through the conservation and reclamation of discarded material.

This department has advanced rapidly especially in the past ten years. Prior to that time, and even up to a few years ago, little attention was given this department by railroad officials. In recent years, however, the development has been so rapid, and credit to operating expense so great, that railroad officials have personally interested themselves in the further advancement and development of this department, to such an extent that a committee composed of officials of this department, representing the American railroads is today one of the outstanding committees of the American Railway Association. The activities of this committee have developed many excellent processes and methods of operation that have resulted in the saving of millions of dollars to our railroads. No other method or practice that I can recall has been more instrumental in the development of this new department, or offers more possibilities to its further advancement than Fusion Welding.

About fifteen years ago a method of fusion welding was introduced to the railroads, at that time a great deal of interest was manifested through this new practice and many operations undertaken without a thorough study of the method involved or results to be obtained, and many operations were attempted, some producing excellent results, both in structure and service, while on the other hand the more difficult and important articles failed in service, resulting in the process being condemned as far as these and similar articles were concerned. This action brought about considerable study, as it did not seem reasonable that an article could be reconditioned by one process and not by another fusion welding method, when the two processes were similar in practice, and where it was possible to complete the work in much shorter period of time by one method and apparently with equally as good results.

Many railroad officials realize today their haste in accepting fusion welding without giving due consideration to the effect to which the article would be subjected, or the possibility of failure, which was due principally to inexperience and lack of knowledge on the part of the operator. This in itself has caused the failure of many articles, but has resulted in more serious study being given the process to pursue, necessity of constant and efficient inspection, supervision, recording of results, service obtained, cost of the operation, and numerous other phases of the entire procedure which are essential and beneficial to the further advancement of fusion welding in so far as the railroads are concerned. While during the advent of fusion welding on our railroads, some serious experiences were encountered. These, however, have brought about more serious thought in connection with the process, and I do not hesitate to state that the experiences of the past will revert to greater development in the very near future. Experiments that are now being conducted by the railroads, and tests that have and are being made warrant this assertion, and I am frank to state that within the next two years we will see wonderful developments from fusion welding on our railroads.

Many of us are perhaps not aware of the possibilities of fusion welding in connection with railroad work. This industry offers a tremendous field for such operations, and many operations have been developed and tested, which will, no doubt, be approved and accepted by the American Railway Association, who are ever eager to further the advancement of any approved method or process that will reduce the cost of maintenance and operation.

The producers of fusion welding apparatus are developing daily further possibilities of this process, likewise the railroad officials are devoting much time and study to further advancement in the railroad field. With the personnel of these two great industries being interested in the same process the possibilities of fusion welding on our railroads is beyond comprehension.

Fatigue and Impact Tests for Welds*

CHAS. H. JENNINGS†

INTRODUCTION

ENGINEERING materials and structures are subjected to two general classes of stresses, namely, static stresses and dynamic stresses. The dynamic stresses can be subdivided into repeated stresses and impact stresses. A third type of dynamic stress known as repeated impact stress is also common but this case is closely related to the more simple case of repeated stress.[1]

In the early stages of development welding was confined to statically stressed structures and the desired information on design strength could be obtained from static tensile and bend tests. However, as welding became applied to dynamically stressed structures,[2] the information obtained from simple static tests was not sufficient because materials behave differently under different stress conditions. Therefore, in order to properly design welded connections subject to dynamic stresses, it became necessary to make dynamic tests on welds such as fatigue and impact tests.

It is the purpose of this paper, therefore, to discuss the need of fatigue tests and the problems encountered in making them, and to present information that has been obtained by the writer on the impact strength of arc welds.

FATIGUE TESTS FOR BUTT WELDS

a. Small Beam Specimens

The first type of welded joint to be extensively investigated under the action of repeated stress was the butt weld because of its simplicity and adaptability to fatigue tests. Numerous investigators have contributed to this work but the technique and procedure of testing have varied widely[3, 4, 5]. As a result, the results obtained have also varied widely.

The fatigue tests made by the company with which the writer is connected have been confined to arc welds, and the results were determined by testing a set of specimens and obtaining a complete stress cycle curve. Also in an effort to obtain a satisfactory test specimen, tests were made on specimens of various sizes. The theory underlying the use of different size specimens is based on the fact that the porosity of the welds causes points of high stress concentration, and that the effect of

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[1] The Fatigue of Metals, by Moore and Kommers, p. 9.

[2] Electrically Welded Structures Under Dynamic Stress, by M. Stone and J. G. Ritter. Journal A.I.E.E., March, 1930, p. 202.

[3] Arc Welding, by Hulse (Fundamental Principles of Welding, by H. Dustin, p. 187).

[4] Strength of Butt Welds, by G. Lobo, Jr. Journal of American Welding Society, April, 1929.

[5] What Is Being Done With Welding at Watertown Arsenal, by Major J. B. Rose. Journal American Welding Society, September, 1929.

this stress concentration depends upon the ratio of the size of the discontinuity to the size of the cross-section of the specimen.[6]

Early tests were made on joints of hot-rolled, low-carbon steel by using a beam type test specimen with an 0.3 in. critical section, as shown in Fig. 1. The testing machine used is shown in Fig. 2.

The welded plates from which the specimens were prepared were made of low-carbon steel and were 10 in. long and ½ in. thick. The welds were made with 5/32 in. bare low-carbon electrodes, using 150 amperes current. In cutting the test pieces from them, ⅝ in. on either end was

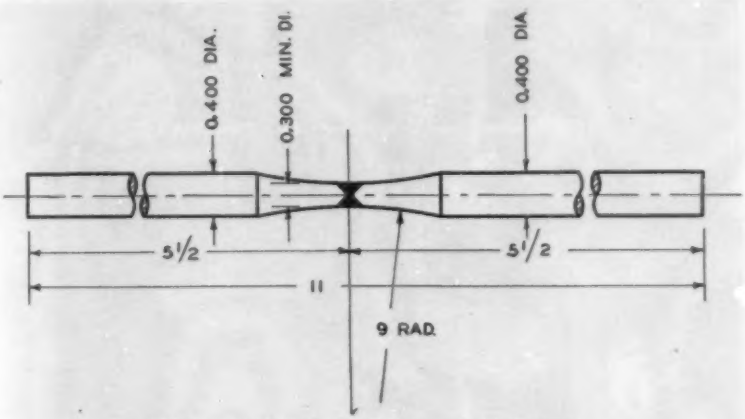


FIG. 1—0.30 DIA. BEAM FATIGUE SPECIMEN

cut off and discarded and the remainder was cut into 12 one-half in. square pieces which, in turn, were machined as per Fig. 1. The types of joints investigated were single and double vee with scarf angles of 0 deg., 30 deg. and 45 deg.

The results of these tests[7] are briefly summarized in Table 1.

TABLE 1

FATIGUE STRENGTH OF BUTT WELDS
(0.3 diameter beam specimens)

Type of Weld	Endurance Limit, Lb./Sq. In.
0°	16,000
30° single vee	21,000
45° single vee	20,100
30° double vee	16,200
45° double vee	17,800

NOTE: Endurance limit of parent metal is 27,000 lb./sq. in.

The curves from which these values were determined are given in Fig. 3.

It will be noted from the curves in Fig. 3 that the points in some cases

[6] Fatigue Tests of Large Specimens, by R. E. Peterson. Trans. A.S.T.M. Vol. 29, Part II, p. 371 (1929).
[7] Strength of Butt Welds, by G. Lobo, Jr. Journal American Welding Society, April, 1929.

are badly scattered. The reason for this is primarily due to the discontinuities in the welds.

b. Small Cantilever Specimens

The next series of tests was made on cantilever specimens of 0.468 diameter critical section, as shown in Fig. 4. The testing machine used is shown in Fig. 5. These specimens were prepared from arc welded low-carbon steel plates 13 in. long and 1 in. thick. The welds were made with 5/32 in. bare low-carbon electrodes, using 150 amperes current.

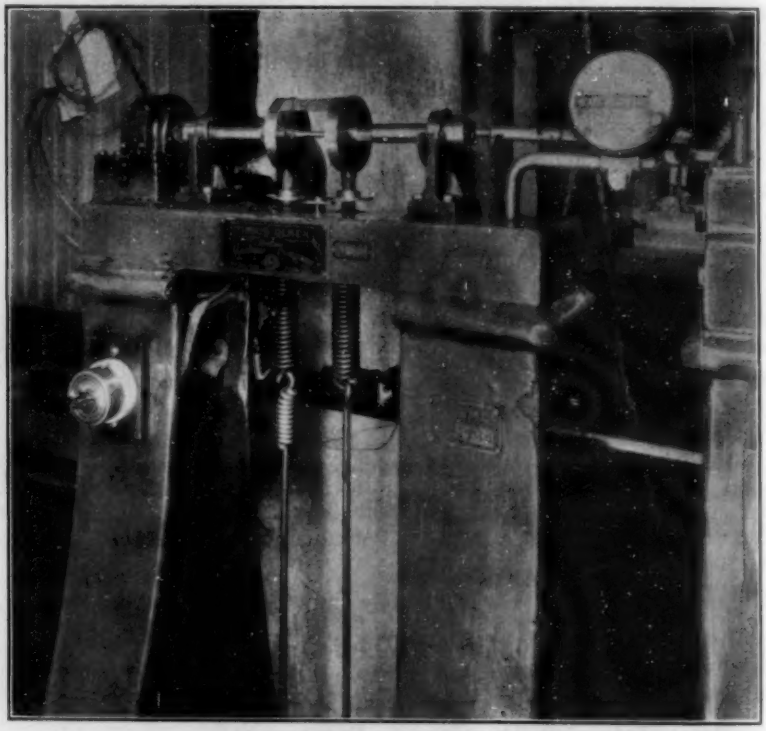


FIG. 2—BEAM FATIGUE MACHINE

About ½ in. on either end of the plates was cut off and discarded and the remaining center portion cut into 10 one-inch square bars. The bars were in turn machined into cantilever specimens, as shown in Fig. 4.

Only one type of joint was tested, using this type of specimen, and that was a double vee 45 deg. weld. The endurance limit obtained in this case was 14,400 lb./sq. in., which was much lower than the value obtained from the 0.3 in. diameter beam specimen. Check tests have been made by other investigators on this type of specimen and the results were in good agreement.

The curve from which this value was obtained is given in Fig. 6. It

will be noted in this case that there was less scatter than was obtained for the beam specimens.

c. Large Cantilever Specimens

Subsequent to the small cantilever tests an investigation was conducted on 2¼ in. cantilever specimens. These specimens were developed at the Westinghouse Research Laboratories.[8] The 2¼ in. testing machine is shown at the right in Fig. 7, and detail sketches of the 2¼ in. specimen and the blanks from which they were prepared are shown in Fig. 8.

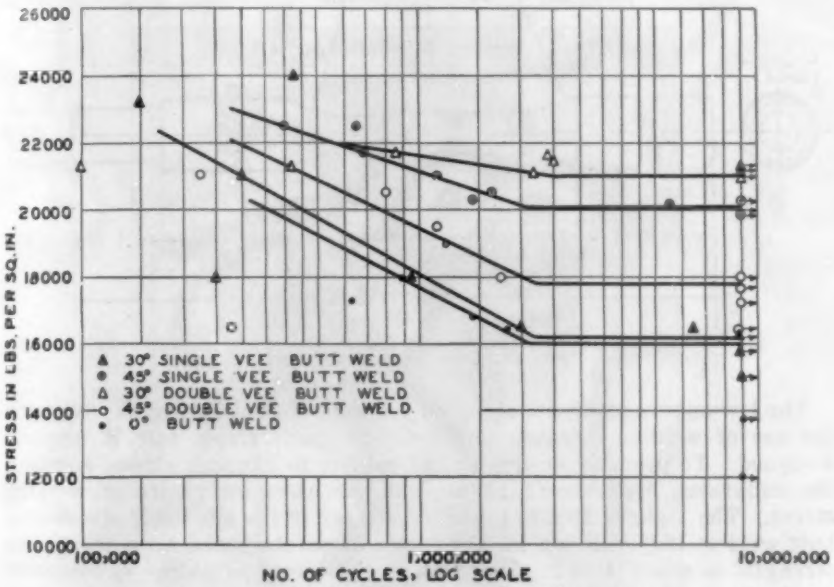


FIG. 3—SHOWING EFFECT OF WELD DESIGN

The specimens were prepared from rough turned blanks of low-carbon steel, as shown in Fig. 8a. The welds were made by using 5/32 in. bare low-carbon electrode, with 150 amperes current. The weld metal was laid in a direction parallel to the axis of the specimen.

The endurance limit as obtained by the 2¼ in. specimens was 10,000 lb./sq. in. The curve from which this value was obtained is shown in Fig. 6. A check test was made on the 2¼ in. specimens one and one-half years later and the results were found to be in good agreement. Some scatter was obtained in this test but it will be noted that a well defined curve was obtained.

d. Discussion of Butt Weld Tests

From the results obtained by the various investigations of butt welds made on low-carbon steel, several important conclusions are obtained.

1. The endurance limits obtained differ for different size specimens.

[8] Fatigue Tests of Large Specimens, by R. E. Peterson. Trans. A.S.T.M., Vol. 29, Part II, p. 371 (1929).

2. The type of joint (single or double vee, etc.) has a marked effect upon the endurance limit.
3. The endurance limit of welds is roughly 1/3 the tensile strength of the welds.

The difference in endurance limits as obtained from different size specimens cannot as yet be explained, but the probable reason is due to the effect of heating and residual stresses. There may, however, be a size effect.

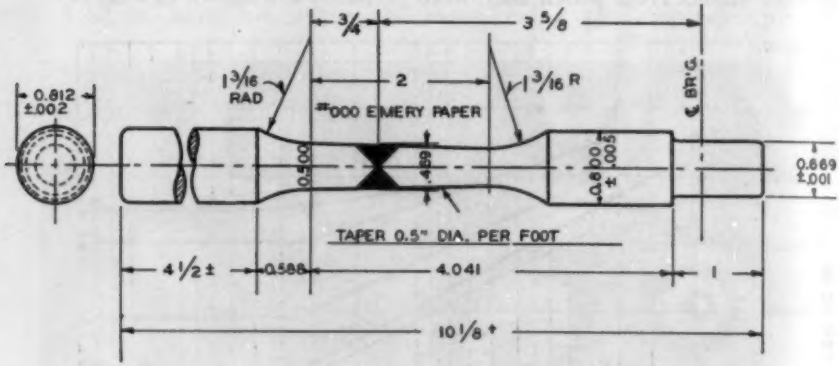


FIG. 4—CANTILEVER TEST PIECE

The low endurance limits obtained for welds do not in any way condemn the use of welding, because joints can be made amply safe if properly designed. To properly design a joint subject to dynamic stress, however, the endurance limit should be used as the basis for choice of working stress. The logic of this is readily seen, for if the allowable stress on a butt weld is 13,000 lb./sq. in. the factor of safety based upon the tensile strength[9] is about 4 to 1. However, if the factor of safety is computed on the basis of endurance limit, as it should be, it would only be about 1.3 to 1.

The fact that different specimens give different values of endurance limits makes it difficult to determine which type of specimen to use for determining endurance limits. However, on the basis of the present knowledge the results obtained on small cantilever specimens are probably satisfactory for ordinary joints. The small cantilever gives fairly consistent results and endurance values, which are lower than those obtained on the 0.3 diameter beam specimens. The choice of a specimen which gives the lowest fatigue values is desirable because any experimental error that might be obtained is on the safe side.

For large welds the use of the large 2¼ in. specimens would be preferable because from the information available large welds tend to be weaker in fatigue than small ones and as a result the values obtained on small specimens would not be satisfactory.

It must be remembered, however, that the above recommendations are

[9] Using 55,000 lb./sq. in. for tensile strength. Using 14,000 lb./sq. in. for endurance limit.

only tentative and that further investigation on this subject might materially change the conclusion obtained at this time.

Fatigue Tests for Fillet Welds

In conjunction with the fatigue investigation on butt welds it was also found desirable to investigate the fatigue of fillet welds. In order to make such tests special large testing equipment was designed so that the fillet welds could be tested by means of large size rotating cantilever specimens.[10] Fig. 7 shows these machines in operation.

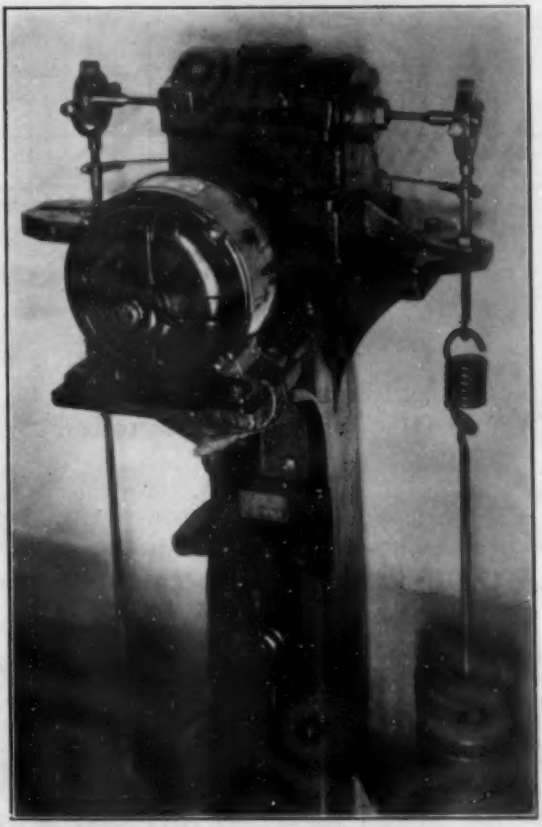


Fig. 5—Small Cantilever Fatigue Machine

The specimens used were prepared from 2 in. diameter blanks of hot-rolled, low-carbon steel, as shown in Fig. 9a. The blanks were tack welded together, while lined up in a jig consisting essentially of an angle in a horizontal plane. The fillet was then completed with the specimen removed and held in a vertical position. All welds were made with bare

[10] Fatigue Tests of Large Specimens, by R. E. Peterson. Trans. A.S.T.M., Vol. 29, Part II, p. 371 (1929).

low-carbon electrodes, using 150 amperes current. After welding the specimens were finish machined, as shown in Fig. 9b. In order to insure smooth running the overhanging bearing ends were machined to size after the specimen was set up in the testing machine.

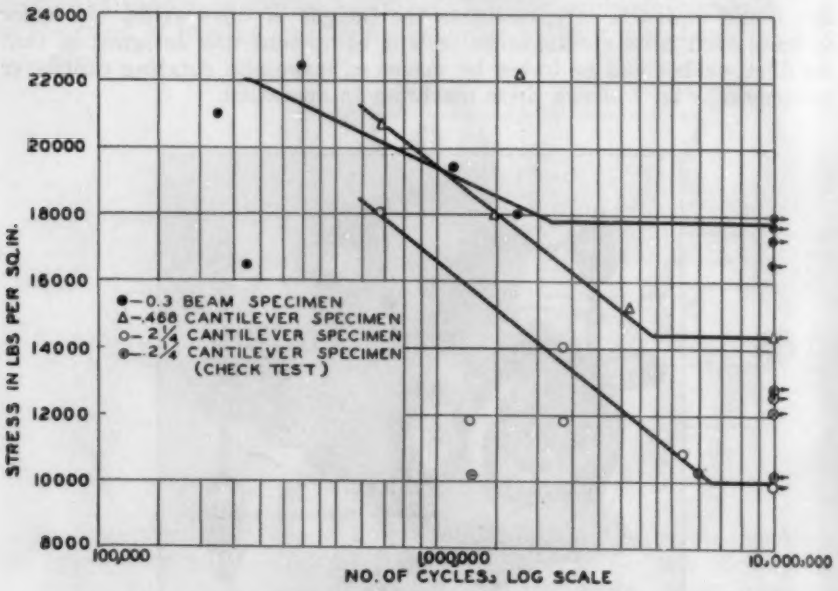


Fig. 6—Showing Effect of Specimen Size

The results of the fillet weld investigations made to date[11] may be briefly summarized as follows:

1. Endurance limits obtained for various fillet welds were—

Type of Weld and Failure	Endurance Limit in Lb./Sq. In.
(1) 0.43″ fillet not machined (failure at base)	18,500
(2) 0.30″ fillet not machined (failure in weld)	18,200
(3) ⅛″ machined radius ¼″ backing	18,800
(4) ¼″ machined radius ¼″ backing	19,500
(5) ⅜″ machined radius ¼″ backing	19,700
(6) 0.85 fillet not machined (failure at base)	17,000
(7) 0.3 fillet machined to 45° sharp corners (failure at base)	14,700
(8) 0.3 fillet not machined (specimen end blanks tapered before welding as per dotted lines as shown in Fig. 9a) (failure at base)	15,200
(9) 0.33 fillet not machined 1/32″ space between parts (failure at base)	12,000
(10) 0.25 fillet not machined 1/32″ space between parts (failure in weld)	11,700

2. Either of two types of failure occurs in fillet welds: failure at the base of the fillet or failure through the fillet.

[11] Fatigue of Fillet Welds, by Peterson and Jennings. Presented before Atlantic City Meeting of A.S.T.M., 1930.

3. For given dimensions of welded parts there is a critical size fillet for which failure occurs both ways simultaneously.

4. For weld sizes below the critical value, failure will occur through the weld metal with lower effective strength. Such failures start at the inside of the fillet.

5. For weld sizes above the limiting value, failure will occur at the base of the weld, the strength remaining substantially the same except for large welds, where a small reduction of strength may be expected.

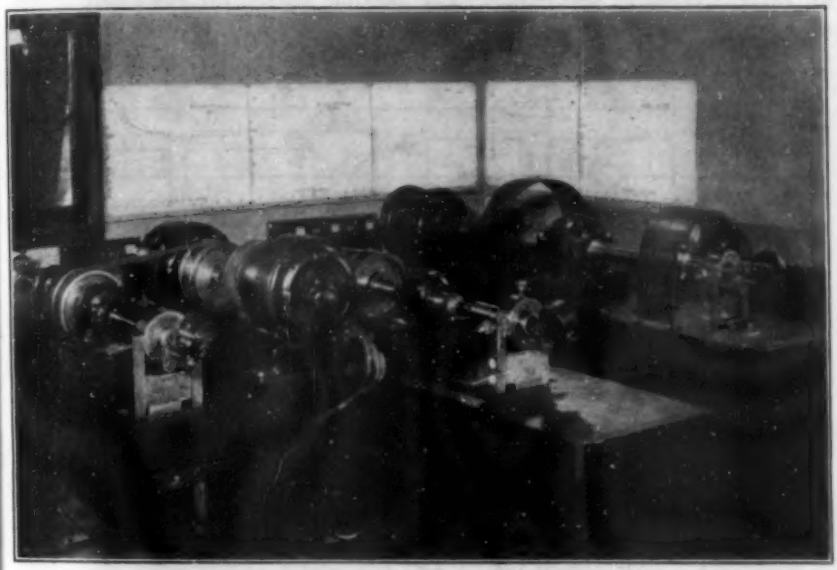


FIG. 7—LARGE FATIGUE TESTING EQUIPMENT

6. Machining a radius at the base of the fillet does not appreciably affect the strength of the fillet.

7. The effect of spacing between the welded parts is to considerably reduce the strength of the weld.

Fig. 10 shows fatigue curves for several types of welds. It is to be noted that all stress values given were computed by applying the flexure formula to the 1 in. diameter section at the base of the weld, marked A-A, Fig. 9b, regardless of the type of fracture. The stresses computed in this manner are not the theoretically correct stress, because of stress concentration and different types of failure. As given, however, all results are on a strictly comparative basis.

The greatly lowered endurance limit of welds with a space between the welded parts is of great importance from the standpoint of design practice. The reason for this reduction in strength is undoubtedly due in part to the fact that the section modulus is somewhat reduced by the separation of the welded parts.

At the present time additional work is in progress by testing fillet welds in fatigue by using a machine of the constant deformation repeated bending type. Results from this work are not available at this time but it is the writer's opinion that valuable information can be obtained by this method.

Impact Tests of Welds

There has been a relatively small amount of work done on impact tests of welds and here again the work that has been done has been conducted on various types of specimens. The possible reason for the small amount of work on this subject is the result of the inability to interpret impact

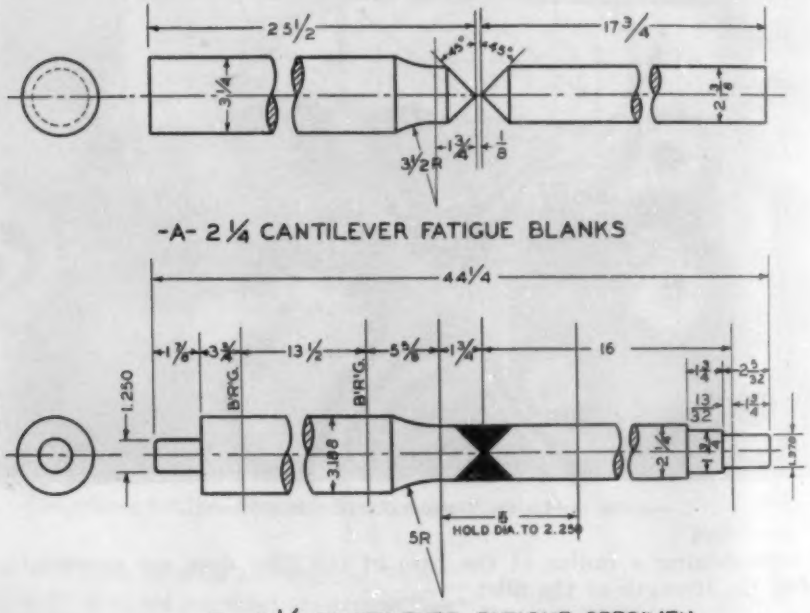
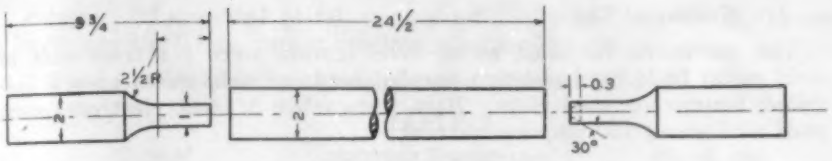


Fig. 8

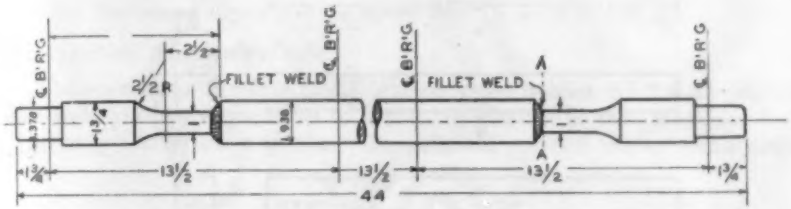
values in terms of design information. It is generally accepted, however, that impact tests do show certain characteristics that static tests fail to do.[13]

The work that has been conducted by the writer has been confined to arc welds and deposited arc weld metal. The square Izod notched specimen was chosen because it eliminated the questionable effect obtained from a round weld specimen, and it made possible the investigation of welds by placing the notch in three different positions with respect to the weld (see Fig. 11).

[13] Applied Elasticity, by Timoshenko and Lessells, p. 418.



a FILLET WELD SPECIMEN BLANKS



b FILLET WELD TEST SPECIMEN

FIG. 9

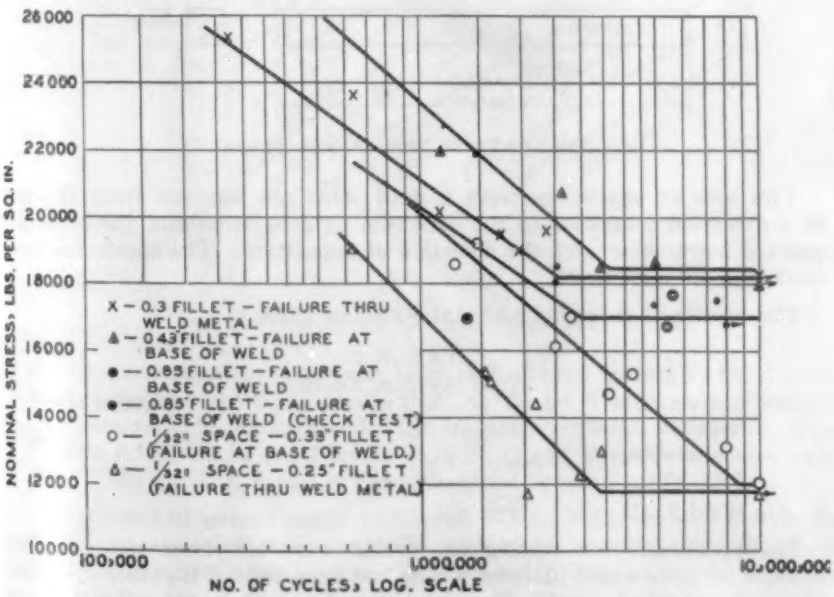

28000
24000
22000
20000
18000
16000
14000
12000
10000
NOMINAL STRESS, LBS. PER SQ. IN.
X — 0.3 FILLET — FAILURE THRU WELD METAL
▲ — 0.43 FILLET — FAILURE AT BASE OF WELD
● — 0.83 FILLET — FAILURE AT BASE OF WELD
● — 0.85 FILLET — FAILURE AT BASE OF WELD (CHECK TEST)
○ — 1/32" SPACE — 0.33" FILLET (FAILURE AT BASE OF WELD.)
△ — 1/32" SPACE — 0.25" FILLET (FAILURE THRU WELD METAL)
100,000
1,000,000
10,000,000
NO. OF CYCLES, LOG. SCALE

FIG. 10—FILLET WELD ENDURANCE CURVES

a. Arc Weldmetal Tests

The specimens for weld metal investigation were cut from pads of weld metal built by depositing parallel beads of weld metal upon a hot-rolled, low-carbon steel plate. Bare, low-carbon 3/16-in. electrodes were used with about 150 amperes current.

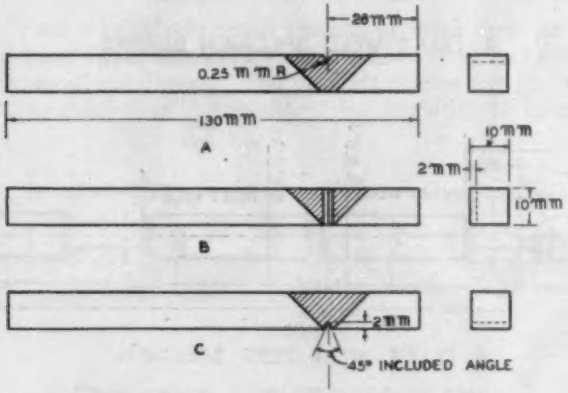


FIG. 11—SINGLE NOTCH IZOD SPECIMEN

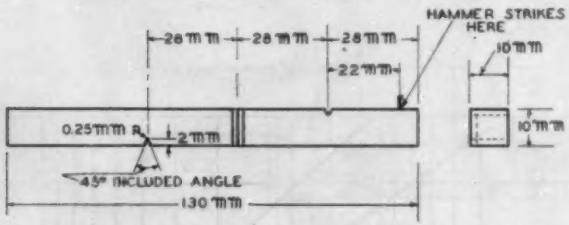


FIG. 12—THREE NOTCH IZOD SPECIMEN

Two sets of specimens were tested. One set was cut from the pad in a direction crosswise to the direction of deposition and the other set was cut lengthwise with the direction of deposition. The specimens were machined as per Fig. 12.

The results of these tests are tabulated in Table 2.

TABLE 2

Direction of Deposited Metal	Average Energy to Fracture in Ft. Lb.	Number of Specimens
Length-wise	15.0	3
Cross-wise	10.0	3

b. Arc Weld Tests

The specimens for testing arc welds were cut from plates ½ in. thick, 6 in. wide and 6 in. long, which had been welded together by means of a 45 deg. single vee weld. The plates were low-carbon, hot-rolled steel and were welded with 5/32 in. bare, low-carbon electrodes, using 150 amperes

current. The welded plates were cut into ½ in. bars which, in turn, were machined into impact specimens as per Fig. 11.

The data obtained from these tests are given in Table 3.

TABLE 3

Type of Specimen	Average Energy to Fracture in Ft. Lb.	Number of Specimens
Fig. 11 (a)	5.5	38
Fig. 11 (b)	5.5	39
Fig. 11 (c)	6.0	39

NOTE: The impact strength of the parent metal is about 80.0 ft. lb.

c. Annealed Arc Weld Tests

The specimens for this investigation were welded with a 45 deg. single vee weld and were prepared in a manner similar to that mentioned above. The only variation was that the original welded plates were annealed

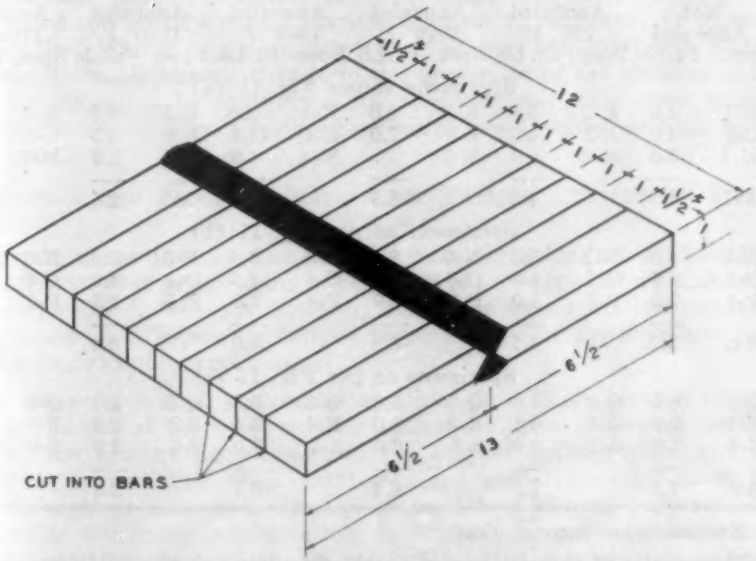


FIG. 13—PREPARATION OF SMALL CANTILEVER BLANKS

at various temperatures for one hour and allowed to cool in the furnace. Nine plates lettered K, L, M, N, O, P, Q, R and S were welded and each plate was in turn machined into six impact specimens. Plates K, L and M were machined as per Fig. 11 (a); N, O and P were machined as per Fig. 11 (b); and Q, R and S were machined as per Fig. 11 (c).

Specimens of parent metal numbered V-1 to V-12, inclusive, were prepared and annealed with the weld specimens in order to compare the results. The specimens were of the three-notch type, as shown in Fig. 12.

The data obtained on the annealed weld investigation are tabulated in Tables 4 and 5.

TABLE 4

IMPACT VALUES OF PARENT METAL IN FT. LB.*

Not Annealed		Annealed 700° F.		Annealed 1000° F.		Annealed 1300° F.		Annealed 1550° F.		Annealed 1700° F.	
Spec.	Ft. Lb.	Spec.	Ft. Lb.	Spec.	Ft. Lb.	Spec.	Ft. Lb.	Spec.	Ft. Lb.	Spec.	Ft. Lb.
V-1		V-2		V-3		V-4		V-5		V-6	
a	76.0	a	79.0	a	74.5	a	80.0	a	22.0	a	30.0
b	81.0	b	81.0	b	81.0	b	78.0	b	25.0	b	35.5
c	81.0	c	81.5	c	74.0	c	79.5	c	24.0	c	32.4
V-10		V-11		V-12		V-7		V-8		V-9	
a	77.5	a	78.0	a	73.5	a	82.5	a	28.5	a	24.0
b	82.5	b	85.5	b	74.8	b	86.5	b	30.5	b	33.0
c	82.0	c	85.5	c	80.0	c	87.5	c	34.5	c	36.0
Av.	80.0		81.5		76.0		82.0		27.4		32.0

*Three notched specimens as per Fig. II.

TABLE 5

IMPACT VALUES OF 45° SINGLE VEE WELDS IN FT. LB.

Not Annealed		Annealed 700° F.		Annealed 1000° F.		Annealed 1300° F.		Annealed 1550° F.		Annealed 1700° F.	
Spec.	Ft. Lb.	Spec.	Ft. Lb.	Spec.	Ft. Lb.	Spec.	Ft. Lb.	Spec.	Ft. Lb.	Spec.	Ft. Lb.
Specimens as per Fig. 11 (a)											
K-1	4.0	K-2	3.5	K-3	4.0	K-4	3.0	K-5	2.0	K-6	2.0
L-1	4.0	L-2	4.0	L-3	7.0	L-4	11.0	L-5	2.5	L-6	2.5
M-1	5.5	M-2	6.0	M-3	..	M-4	4.0	M-5	2.0	M-6	3.0
Av.	4.5		4.5		5.5		6.0		2.5		2.5
Specimens as per Fig. 11 (b)											
N-1	4.0	N-2	5.0	N-3	8.0	N-4	5.0	N-5	2.0	N-6	2.5
O-1	6.0	O-2	4.0	O-3	7.5	O-4	4.5	O-5	4.0	O-6	2.5
P-1	7.0	P-2	5.0	P-3	5.0	P-4	2.5	P-5	2.5	P-6	2.0
Av.	5.7		4.7		6.8		4.0		3.0		2.3
Specimens as per Fig. 11 (c)											
Q-1	6.5	Q-2	7.0	Q-3	5.0	Q-4	5.5	Q-5	2.0	Q-6	4.0
R-1	9.0	R-2	6.0	R-3	8.0	R-4	6.0	R-5	2.0	R-6	2.0
S-1	7.0	S-2	9.0	S-3	6.0	S-4	7.0	S-5	3.0	S-6	3.0
Av.	7.5		7.3		6.4		6.1		2.3		3.0

d. Summary on Impact Tests

The results of these data can be briefly summarized as follows:

1. The impact strength of deposited weld metal depends upon the direction of the applied load with respect to the direction of weld metal deposition.

2. The impact strength of deposited weld metal is greater than the impact strength of a welded joint.

3. The impact strength of a 45 deg. single vee joint made with a bare low-carbon electrode is about 5.5 ft. lb., which is only about 1/15 the impact strength of the parent metal.

4. Annealing temperatures up to 1550 deg. do not appreciably affect the impact strength of the welds. For annealing temperatures of 1550 deg. and 1700 deg. Fahr., the impact strength is greatly reduced.

5. Similar reduced impact values are obtained for annealed parent metal.

6. In most cases the location of the notch with respect to the weld has little effect upon the impact strength.

The fact that welds give low impact values is probably due to the condition of the deposited metal which is essentially a cast material. As mentioned before, impact values cannot be interpreted in design information; therefore, the low impact values obtained for welds must not be interpreted to mean that the welds are unsatisfactory for structures subject to shock, as that is not the case.

"The ability of welded joints to resist fatigue and shock satisfactorily is primarily conditioned on the use of materials suitable for welding and good design."[13]

Knowing that impact test results cannot be interpreted in terms of the other physical properties of the material one might question the advisability of such tests. The answer to this is clearly illustrated in the tests on annealed specimens where a marked decrease in resistance to impact was obtained for specimens annealed at 1550 deg. and 1700 deg. Fahr. The tests definitely show a change in the properties of the material that would not be shown by ordinary static tensile tests. This alone might warrant the use of impact tests where welds are annealed at high temperatures.

Conclusions and Recommendations for Fatigue and Impact Tests for Welds

From the above discussion on dynamic tests for welds it is evident that there are a number of problems to be solved before satisfactory standard tests are obtained. There is, however, a need for some tentative standard for dynamic tests, especially fatigue tests, because of the extensive use of welds in dynamic structures.

The proper choice of a standard specimen is difficult because of the effect of the size of the welds on their endurance limit. However, on the basis of the present knowledge and the cost of making tests and of testing equipment the small cantilever specimen (Fig. 4) tends to show the most promise as a suitable standard for ordinary purposes. If large welds are under consideration, however, this small specimen may not give satisfactory results. No recommendation can be made at this time as to standardization of fatigue tests for fillet welds.

In preparing butt weld fatigue specimens for investigating welded joints a convenient procedure would be as follows:

1. Prepare two plates of dimensions 6½ in. x 12 in. x 1 in. thick, as shown in Fig. 13, and weld these together by using the desired electrode and current (any type of joint desired can be used). Care should be taken in welding so that very little warping takes place.

2. Cut the welded plates into eight 1-in. square bars from the center portion and discard the remaining ends (see Fig. 13).

[13] Arc Welding, by Hulse, p. 53. (Article on Arc Welding—Its Fundamentals and Economics, by J. W. Owens).

3. Machine the eight bars into cantilever specimens as per Fig. 4.

4. Test the specimens at various stresses so as to obtain a complete endurance curve. This is done by applying decreasing values of stress on consecutive specimens until a stress of such a value is obtained that the specimen will not break after any number of cycles of repeated stress. For ordinary steels it has been found that the endurance curve becomes flat before 10,000,000 cycles of stress (see Figs. 3, 6, and 10). Therefore, if a specimen does not break before 10,000,000 cycles of stress, it can be considered to be stressed at a value equal to or below the endurance limit.

Regarding the standardization of an impact test, it is the writer's opinion that on the basis of the available information no one test can be recommended. The information presented shows the value of impact tests but it is not extensive enough to warrant any recommendations. It would be highly desirable, however, if some systematic investigation could be made by using different types of specimens and from these results it might be possible to standardize on some type of specimen.

ACKNOWLEDGMENTS

The author wishes to give particular acknowledgment to R. E. Peterson and G. Lobo, Jr., for their assistance in obtaining the information included in this paper.

Note on the Use of Gamma Rays for Examining Welds*

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A STUDY has recently been made[1] of the possibility of using gamma rays from radium emanation to examine such objects as heavy castings and welds for internal defects. A note on the method may be of interest to those concerned in the extension of the welding art.

The apparatus necessary for radiography by gamma rays is extremely simple. In place of an X-ray apparatus, composed of a transformer, low and high voltage wires and an X-ray tube with cooling and control devices, the radium apparatus may consist simply of a capsule about the size of a 22 caliber cartridge containing the source of rays. The portability of such a capsule would allow it to be used in such places as the top of a partly constructed bridge or skyscraper, the interior of complex steel frameworks, or even under water. It becomes possible, then, to radiograph welds in places inaccessible to the usual radiographic apparatus. The bulb of radium emanation is supported in front of the

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[1] "Radiography by the Use of Gamma Rays," Mehl, Doan and Barrett, Trans. A.S.S.T., 1930.

weld, and a photographic film in a light tight envelope fastened behind the weld. At the end of a length of time determined by the amount of radium used, the thickness of the weld, the distance from the bulb to the film, and the amount of detail desired, the film is removed and developed. Flaws in the weld show up on the film just as in the usual X-ray radiographs.

Gamma rays are similar to X-rays that would be obtained from an X-ray tube operating at several million volts instead of one or two hundred thousand volts as in ordinary radiography. They have the power of penetrating much greater thicknesses than X-rays, allowing radio-

FIG. 1

FIG. 2

graphs to be taken through about a foot of steel, while X-ray radiography is limited to thicknesses of 3½ in. or less. On the one hand this high penetrating power causes defects to show up on the film with less contrast than when X-rays are used, but on the other hand, good pictures of irregular thicknesses are made easier to obtain, and "halation" effects at the edges of the objects are almost completely absent.

It is too early to give data on the cost of inspection by this method. It can be made very reasonable, however. It is not necessary to buy radium, for it can be rented from hospitals in various cities. Exposures can be made at night when the radium is not being used at the hospitals, reducing the rental to a minimum rate. Since the rays are emitted in all directions from a source, time and cost may be minimized by placing a large number of test objects about the source and taking a dozen or more photographs simultaneously.

Inspection may be carried out without a lead lined room, yet with complete safety to the operators. Distance from the source is the best protection. This is easily provided if the object and films are arranged about the empty container for the radioactive material during the day, and the exposure made at night when no one is in the room.

Two gamma ray radiographs of welds are reproduced here. Fig. 1, an arc weld between two 1 in. steel plates, shows an almost continuous line of non-metallic inclusions and blow holes through the center of the weld. The weld itself is about ¾ in. wide and appears lighter than the rest of the plate. This is due to slight building up of the weld, making it thicker than the plates and thus absorbing more of the radiation. Fig. 2, an arc weld between two lapped ½ in. steel plates shows lack of fusion to the upper plate. The weld metal is merely deposited adjacent to the edge of the upper plate but not welded to it. While the contrast in these pictures is not great, it is seen to be ample to show the various defects in welds. (Much detail is, of course, lost in reproduction).

Work is being continued to determine minimum times of exposure necessary for good photographs and to develop other refinements.

Extracts Report on Strength of Welded Joints in Tubular Members for Aircraft*

By H. L. Whittemore† and W. C. Brueggeman†

I. INTRODUCTION

THIS investigation was made by the Bureau of Standards in cooperation with the National Advisory Committee for Aeronautics for the Aeronautics Branch of the Department of Commerce. The object of the investigation is to make available to the aircraft industry authoritative information on the strength, weight, and cost of a number of types of welded joints. This information will, also, assist the Aeronautics Branch in its work of licensing planes by providing data from which the strength of a given joint may be estimated. As very little material on the strength of aircraft welds has been published,[1] it is believed that such tests made by a disinterested governmental laboratory should be of considerable value to the aircraft industry.

Following the program prepared from information supplied by manufacturers, 40 joints were welded under procedure specifications and tested to determine their strengths. The weight and time required to fabricate were also measured for each joint.

II. ACKNOWLEDGMENTS

Acknowledgment is made to the naval air station, Anacostia, D. C., for welding some preliminary test specimens; to the Linde Air Products Co., the Air Reduction Sales Co., the Bastian-Blessing Co., and the Torchweld Equipment Co. for lending the torches and equipment used; to the Fokker Airplane Co. for assistance in obtaining a welder; to the Air Reduction Sales Co. for the welding supervisor; and to Dr. Lennart Andren, Mr. W. H. Parker, Mr. W. G. Rinehart, and Mr. Robert Patterson, of the Research Department of the American Chain Co., for making flame and weldability tests of the material.

III. MATERIAL

1. Physical Properties

Chromium-molybdenum seamless steel tubing was used to make all the test specimens. Chromium-molybdenum sheet steel of the same chemical analysis as the tubing was used in making reinforced joints. The tubes complied with United States Army Specification No. 57-180-2A and the sheet steel with Navy Department Specification No. 47S14. *Editor's Note: The physical properties and chemical composition are given in the December, 1928, issue of the Journal of the A. W. S.*

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*Report published by National Advisory Committee for Aeronautics as report No. 348. Paper to be presented at Fall Meeting of the A. W. S., September, 1930.

†U. S. Bureau of Standards.

[1] See Bibliography for a list publications on this subject.

Welding wire conforming to American Welding Society Specification for Gas Welding Rods G-No. 1A[2] was used.

Sizes of the tubing used for specimens is given in Table I.

TABLE I

Tubing Sizes

Outside Diameter, Inches	Wall Thickness, Inch
¾	0.028
1	.035
1⅛	.049
1½	.058
2	.065

Typical physical properties of the material in tension and in compression are given in Table II. One tensile and one compressive specimen were cut from each end of each tube used. The strengths of the tubes were used to determine compliance with the specifications and in calculating the efficiencies of the joints. Stress-strain diagrams were made from extensometer runs on tensile and compressive specimens taken from ten tubes. The physical properties of these specimens are given in Table II. Some of the properties of specimens cut from opposite ends of the same tubes are listed for comparison.

TABLE II—TYPICAL PHYSICAL PROPERTIES OF TUBING

Size	Tube No.	Tension					Compression		
		Proportional limit	Yield point	Ultimate strength	Modulus of elasticity	Elongation in 2 inches	Proportional limit	Ultimate strength	Modulus of elasticity
		Lbs./in.²	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*	*Per cent*	*Lbs./in.²*	*Lbs./in.²*	*Lbs./in.²*
¾×0.028	267	45,000	116,800	125,100	27,000,000	10	68,700	119,200	29,300,000
			118,700	125,400		12		119,400	
	200	44,000	75,800	86,500	28,300,000	18	50,000	87,000	28,800,000
			84,400	88,200		15		86,600	
1×0.035	182	41,000	86,700	97,500	27,200,000	10	62,100	95,200	30,000,000
			90,200	94,300		16		95,600	
	196	62,800	115,400	122,000	28,400,000	11	93,900	115,200	28,700,000
			115,100	121,500		14		117,900	
1¼×0.049	253	41,300	94,200	100,000	28,300,000	18	46,700	94,800	29,600,000
			92,000	104,000		19		96,800	
	256	57,300	100,000	109,000	28,700,000	18	67,400	94,700	28,800,000
			102,800	107,100		21		108,400	
1½×0.058	42	53,500	91,200	100,400	28,300,000	27	60,300	89,700	28,600,000
			88,200	96,800		31		84,000	
	102	44,700	79,800	98,700	28,300,000	25	50,200	89,400	27,100,000
			88,800	101,600		27		97,600	
2×0.065	152	56,500	108,300	111,800	29,800,000	26	103,900	105,100	30,600,000
			93,800	94,900		22		107,900	
	151	60,200	112,600	113,100	29,200,000	19	42,200	97,200	29,800,000
			95,900	96,000		23		101,800	
Average		50,000	98,000	105,100	28,400,000	19	65,100	100,200	29,100,000

Tensile specimens were taken from the tubing in full section, and the ends plugged with round-ended plugs. An Amsler testing machine was used for testing all specimens. The yield point was determined by the "drop of the beam" method. The compressive specimens were made with

[2] This specification is identical in its essential requirements with U. S. Ordance Department Metal Specification No. 57-203-A, grade E.

a slenderness ratio $\left(\frac{l}{r}\right)$ equal to 15 and were tested in a special fixture for ensuring round-end conditions. The extensometers used were the Ewing, used on a 2-inch gage length and the Huggenberger with a 1-inch gage length.

The proportional limit was determined by the method proposed by Dr. L. B. Tuckerman,[3] in which the deviation of the stress-strain curve from a straight line was determined by using the least count of the extensometer as a criterion.

The average variation of strength in specimens cut from opposite ends of tubes of lengths varying from 8 to 15 ft. was approximately 3 per cent. In several tubes there was as much as 15 per cent difference.

One sheet of 0.063-in. plate 18 in. wide was used in making all reinforcements requiring material of this thickness. Four tensile specimens in the form of coupons with a 2-in. gage length and a parallel section ½ in. wide by 3 in. long were cut from this sheet.

Results of the test of these specimens are given in Table III.

TABLE III

Strength of Coupons From 0.063-Inch Chromium-Molybdenum Steel Plate

Specimen No.	Yield Point, Lbs./In.²	Ultimate Strength, Lbs./In.²	Elongation in 2 Inches, Per Cent
1	59,120	76,900	21
2	59,400	81,900	22
3	57,600	75,800	22
4	60,000	81,200	21
Average	59,000	79,000	21.5

TABLE IV

Chemical Analysis of Tubing

	No. 155 2 In. × 0.065 In. Per Cent	No. 251 1⅛ In. × 0.049 In. Per Cent	No. 287 ¾ In. × 0.028 In. Per Cent
Carbon	0.31	0.30	0.31
Manganese	.49	.49	.46
Silicon	.13	.17	.15
Chromium	.99	.97	.96
Nickel	.09	.12	.14
Molybdenum	.24	.22	.23
Vanadium	.03	.01	.01

[3] See Discussion by L. B. Tuckerman of The Determination and Significance of the Proportional Limit in the Testing of Metals, by R. L. Templin, presented at the Thirty-second Meeting of the American Society for Testing Materials, June 25, 1929.

TABLE V

Chemical Analysis of Welding Wire

Lot	Diameter Inch	Carbon Per Cent	Manganese Per Cent
1	1/16	0.02	0.01
2	1/16	.02	.02
3	1/8	.02	.02
4	3/32	.01	.02

2. Chemical Composition[4]

a. Tubing

Results of chemical analyses of one sample of each of three tubes are given in Table IV.

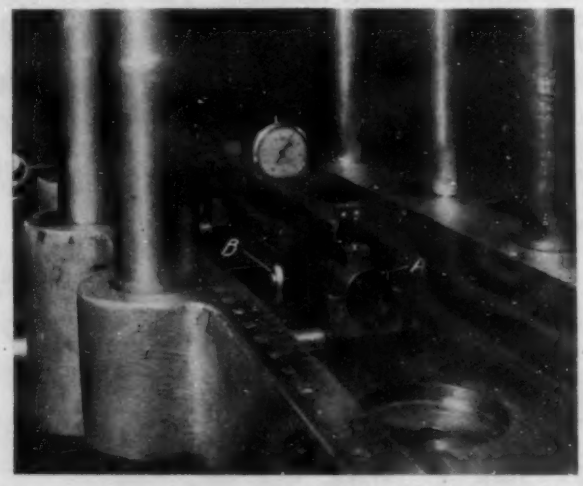


Fig. 1—Fixture for Testing T Joints in Amsler Machine, Loading I. The Vertical Member B is Loaded in Tension Until the Required Permanent Deflection at Midspan is Reached

b. Welding Wire

Analysis of the welding wire used is given in Table V.

3. Welding Properties

a. Tubing

Samples of the tubing were subjected to a flame test applied to the end of the sample and to the wall surface. The indications were that the metal behaved as a clean, quiet material under the torch.

b. Welding Wire

The samples of the welding wire were also subjected to this test. Lots Nos. 1, 2, and 4 of the 1/16, 1/16, and 1/32 in. size, respectively, were

[4] Chemical analyses, flame, and weldability tests of the tubing and welding wire were made by the Research Department of the American Chain Co. The following report of these tests is taken from their Test No. 91, Welding Wire and Chrome-Molybdenum Tubing for Aircraft, Bureau of Standards.

of too small a diameter for a proper interpretation of this test, as no boiling action could occur even if the conditions which would produce such boiling were present. Lot No. 3 of ⅛-in. size showed slight amounts of impurities under the copper coating but not in amounts great enough to interfere with the welding qualities of this lot. The impurities were

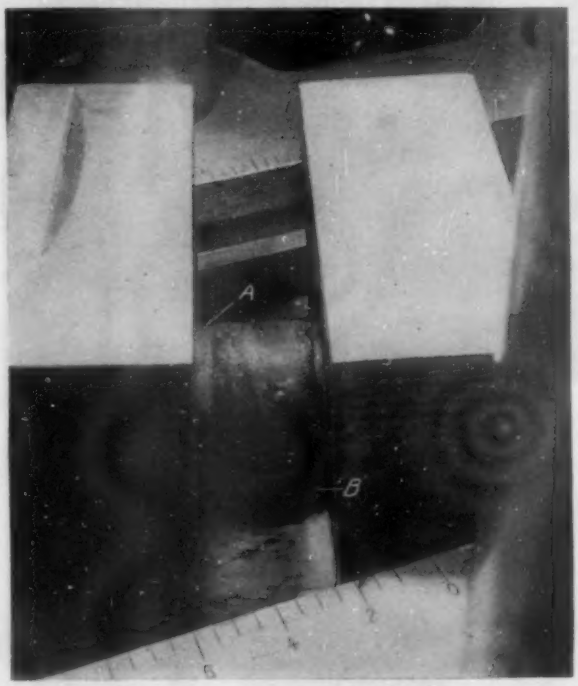


FIG. 2—FIXTURES FOR TESTING T JOINTS IN AMSLER MACHINE, LOADING II. THE STEEL BLOCKS ARE SLIPPED OVER THE ENDS OF TUBE A. SLIP COLLARS ARE USED TO ADAPT IT TO VARYING SIZES OF TUBE A, AND THE BLOCKS ARE MADE WITH SLOTS IN THE BOTTOM TO CLEAR THE GUSSET PLATES WHEN USED. THE OTHER END OF TUBE B IS GRIPPED IN THE FIXED JAWS OF THE MACHINE, AND TUBE B IS LOCATED IN TENSION UNTIL FAILURE OCCURS

only noticeable in the flame test. All the samples showed good welding properties when used on the tubing. Due to the alloy content in the base metal some scale was formed on the welds, but when tried out in actual welding on Armco sheets nothing objectionable could be found in any of the lots submitted.

Six butt joints were made with each one of the four lots of wire submitted. Wire from each end of each coil was used to weld the samples of tubing together. No difficulty whatsoever was encountered in these tests.

IV. SPECIMENS

1. *Description*

The joints may be grouped into butt joints, T joints, and lattice joints. Drawings of the joints are shown in Figs. 10, 14, 15, 16, 18, 19 and 20. It

is believed that most types of joints used in aircraft structures are represented and that a close estimate of the strength of any joint can be made by referring to the test results of one or more of the specimens. Although butt joints are seldom used to carry direct tension or compression in aircraft structures, they were included in the program to determine the properties of the metal near the weld.

FIG. 3—FIXTURE FOR TESTING LATTICE JOINTS. TUBES A AND C ARE SUPPORTED ON PIN BEARINGS WHILE TUBE B IS LOADED IN TENSION UNTIL FAILURE OCCURS

Three specimens were made of each joint. Each specimen was given a number, the first digit referring to the type of joint, the second to the size, and the last to the number 1, 2, or 3 arbitrarily assigned to specimens of the same type and size. Thus, specimen 243 is the third of the triplicate inserted-gusset T joints of type 2 and size 4. When reference is made to the triplicate specimens, the type and size number is used followed by a cipher. Thus, joint 240 is all of the joints of type 2 and size 4.

Specimens of the butt joints were made for both tensile and compressive tests. A slenderness ratio $\left(\frac{l}{r}\right)$ equal to 15 was used for the compressive specimens. In addition to determining the strength and efficiency of the butt joints, hardness explorations and stress strain measurements were made of several joints in order to study the properties of the metal in the region in which failure occurred.

In the T joints, tubes A and B meet at an angle of 90 deg. In all the

lattice joints except No. 680 the angle between intersecting tubes is 60 deg. In joint No. 680 an angle of 45 deg. is used. Both T and lattice joints were made without reinforcement by machining the ends of

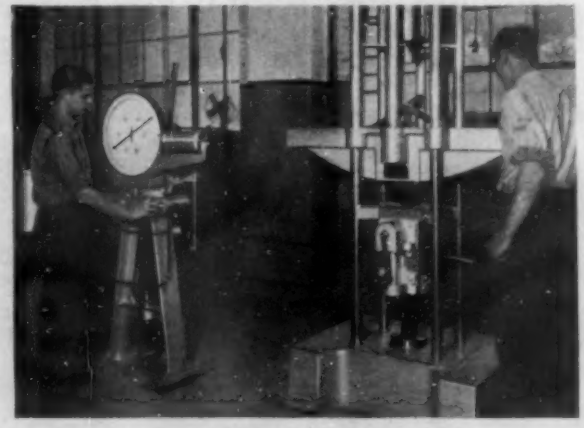


FIG. 4—A LATTICE JOINT BEING TESTED

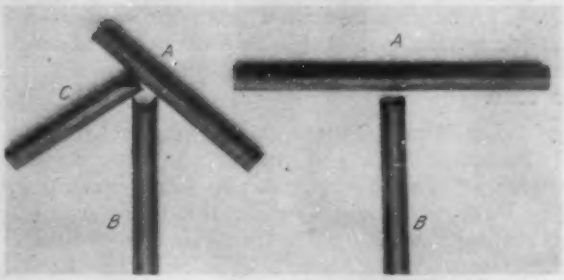


FIG. 5—TUBES COMPOSING A T AND A LATTICE JOINT SHOWING TUBE ENDS MACHINED BY SPIRAL END MILLS

tubes B and C to fit around the wall of tube A, then welding. Tubes ranging in size from ¾ in. outside diameter by 0.028 in. in wall thickness (hereafter abbreviated ¾ in. × 0.028) to 2 in. × 0.065 were used. In some joints all tubes were the same size and in others the secondary or "lattice" tubes (B or B and C) were made three-fourths the diameter of tube A. Three specimens of each joint were tested.

In addition, joints were made with reinforcement such as plates, straps, etc., welded to the tubes at the joint to determine if reinforcing increased the strength. To avoid too great a number of specimens, all reinforced joints were made in one size of tubing 1½ in. × 0.058.

2. *Method of Testing*

An Amsler testing machine with load capacities of 0-10,000, 0-20,000, 0-50,000 and 0-100,000 pounds was used for all tests.

T joints were given two tests designated as loading I and II. Loading

I is a transverse test of tube A (see drawings) in which this tube was supported on rollers at the ends of a span equal to 10 diameters with the joint in the middle. (Fig. 1) The deflection was measured by a dial micrometer fastened to an angle bar which was attached to tube A above the supports through flexure plates. Tube B was plugged and loaded in tension until either the specimen failed or a well-defined permanent deflection was reached. The specimen was then given loading II, designed to determine the ultimate strength of the joint when loaded on a short span. Two blocks (see Fig. 2) were placed as close to the joint as possible. Tube B was again loaded in tension until failure occurred. Loading I was considered of greater importance than loading II, as it is believed that tube A would seldom be supported on a span less than 10 diameters in an aircraft structure.

For testing the lattice joints the fixture shown in Fig. 3 was used. It was designed to support the ends of tubes A and C on pin bearings while tube B is loaded in tension. The fixture was placed on the moveable head of the testing machine as shown in Figs. 3 and 4.

3. *Machining*

The pieces for corresponding members of the triplicate specimens of each type were cut from the same tube. The cross-sectional area of each tube was computed by dividing the weight by the product of length times density. It was also computed from the measured diameter and wall thickness for a number of tubes as a check. The average difference in the computed areas of 14 tubes measured by both methods was less than 0.5 per cent.

The ends of tubes B and C were shaped in the milling machine to fit tube A closely by using spiral end mills of the same diameter as tube A. Sharp edges were afterward removed. In joints having inserted plates such as 230 and 750, slots were cut in the tubes using screw-slotting cutters in the milling machine. The time required to machine each joint was observed.

The pieces for a T and a lattice joint are shown in Fig. 5 ready for welding.

4. *Welding*

It was considered of the utmost importance that all the welding done in this investigation should be uniform and of good commercial quality. It was realized that the test results would be of little value unless the physical properties of the welds as well as the properties of the base metal and the designs of the joints were fixed and reproducible. As procedure specifications are receiving considerable attention as a means for ensuring high-grade welding, it was decided that the welding be done under specifications especially prepared for aircraft structures. The American Bureau of Welding was requested to supply procedure specifications and appointed a Committee on Welding Procedure which prepared specifications for oxyacetylene welding.* The specifications for electric welding have not yet been prepared.

The Bureau of Standards employed Mr. M. I. Anderson, who welded

*Published in December, 1928, issue Journal of the American Welding Society.

all the joints. His experience had been obtained at the Keystone Aircraft Corporation and the Fokker Aircraft Corporation. He complied with the qualification tests of the procedure specifications.

The Air Reduction Sales Co. contributed the services of Mr. A. Rath, a member of its staff, as welding supervisor. He was present during all the welding. In his opinion, it complied with the procedure specifications.

In order to use representative apparatus, four of the principal manu-

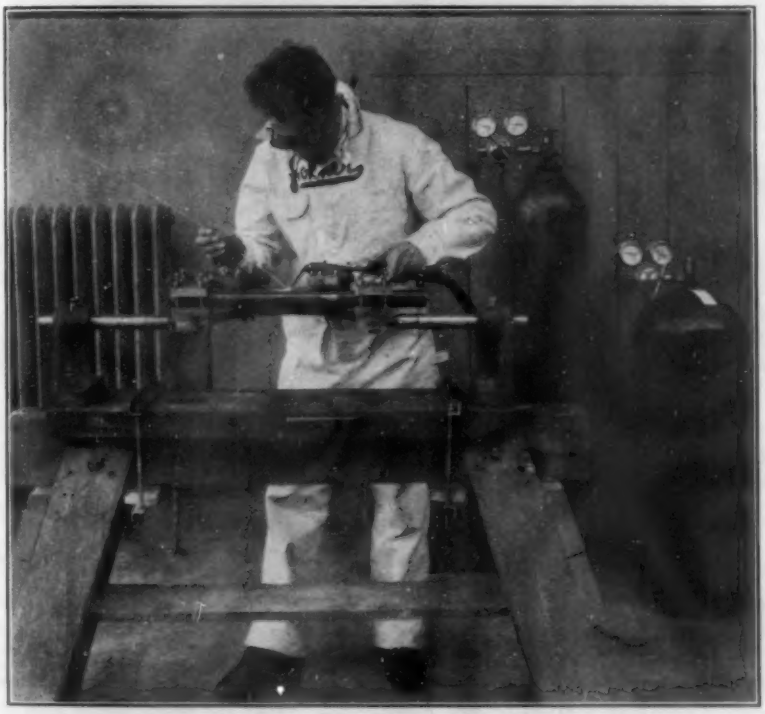


FIG. 6—A LATTICE JOINT BEING WELDED IN THE JIG

facturers of welding equipment were invited to submit a complete set of their apparatus for use in welding the test specimens. Each set was used to weld specimens assigned to it when the program was prepared. The sets are designated by the letters A, B, C, and D.

The oxygen and acetylene were purchased from the contractor given in the general schedule of supplies for the fiscal year 1929, prepared by the General Supply Committee of the Treasury Department.

Analysis of the oxygen showed a purity of 99.5 per cent. No analysis was made of the acetylene, but it complied with the specifications used by the United States navy yard, Washington, D. C., in purchasing this gas. These specifications are as follows:

The acetylene gas shall be dissolved in sufficient acetone to insure against explosion and shall be purified to the highest possible degree of purity, the hydrogen and sulphur being removed to such an extent that the gas will not color a piece of white blotting paper or similar material saturated in a 5 per cent solution of silver nitrate when held in the flow of the gas for 30 seconds.

The specimens were welded in a jig (see Fig. 6 and 7) which was adjustable to fit all joints in the program. By mounting the jig in

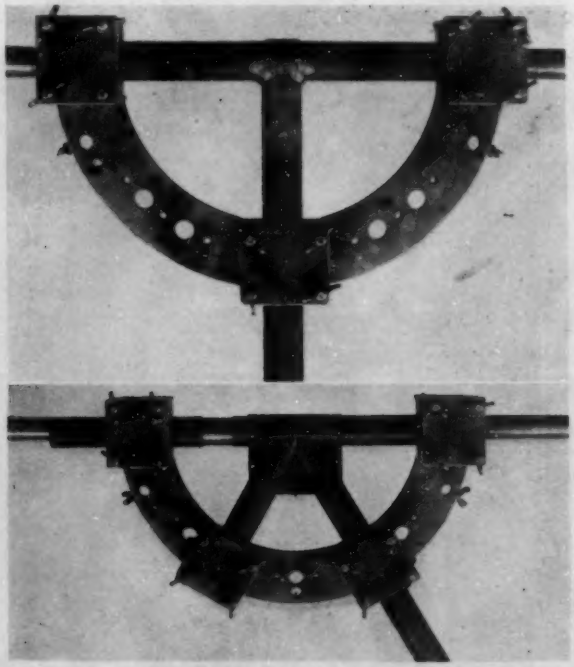


FIG. 7—A T JOINT (UPPER) AND A LATTICE JOINT (LOWER) SET UP IN THE JIG FOR WELDING. THE TUBES ARE CLAMPED IN V BLOCKS BOLTED TO THE FRAME. WHERE TUBES OF DIFFERENT DIAMETER WERE WELDED TOGETHER, SHIMS WERE PLACED UNDER THE BLOCKS HOLDING THE SMALL TUBES. THE JIG MAY BE TURNED OVER FOR WELDING ON THE BOTTOM SIDE

bearings so that it could be rotated, all parts of the joint were readily accessible to the welder.

The pieces of each joint were weighed before welding, and the joint was weighed after welding, the difference being the weight of the weld metal. As a check the bundle of welding wire used for each joint was weighed before and after welding, and the amount used was compared with the increase in weight. The weight of welding wire used was found to be about 10 per cent higher than the gain in weight of the pieces during welding.

In making the butt joints in tubes of 0.028 and 0.065 in. wall thickness, it was impossible to make beads of the dimensions given in Fig. A of the procedure specifications. The actual dimensions are given in Fig. 8,

For the thinnest base metal the bead is slightly wider but of less height than specified. For the thickest base metal both width and height are less. It is believed that an increase in bead size would not affect the test results as the majority of the specimens failed outside the weld.

By far the most serious difficulty encountered in the welding was the formation of cracks in the gusset plates. About one-fourth of all joints reinforced with plates had visible cracks. The numbers of such joints

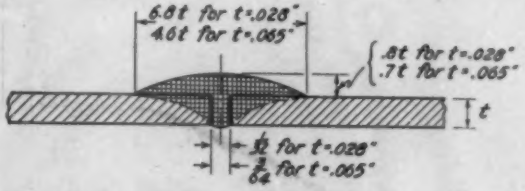


FIG. 8—DIMENSIONS AT SECTIONS OF BUTT JOINTS IN TUBING. A SOMEWHAT SMALLER BEAD WAS USED THAN THAT PRESCRIBED IN FIG. A OF THE PROCEDURE SPECIFICATIONS

are 2251, 2252, 2253, 431, 441, 442, 452, 532, 751, 753, 7191, 7192, 851, 931, and 932. Photographs of the cracks in joints 753 and 851 are shown in Fig. 9. Changing the order in which the welds were made or the direction of welding appeared to have no effect on the cracking.[5] Welding on one side only of plates not inserted in the tube was tried in joints Nos. 432, 433, and 453. No cracks were noted in these joints.

In testing specimens Nos. 2251, 2252, 2253, 431, and 532 the fracture started in a visible crack, probably resulting in a lower ultimate strength. It is believed that the strengths of the other specimens were not affected by cracks.

V. TEST RESULTS

1. *Butt Joints*

Tensile and compressive tests were made of butt joints in the five sizes of tubing. The efficiencies and maximum stresses are plotted in Fig. 10. The efficiencies ranged from 78 and 93 per cent for both tension and compression based on the strength of the unwelded tube. There was apparently no relation between the efficiency and the size of the tube. Failure in all except one joint, No. 052, occurred in the tube about one-half inch from the weld. Tensile specimens failed to rupture at this point, and compressive specimens by formation of a circumferential fold.

To study the properties of the metal as affected by the heat of welding in the region in which failure occurred, hardness explorations and stress-strain measurements were made of the butt joints.

Hardness explorations were made of joints 011, 041, and 051, using a Vickers machine with a 30-kg. load applied for 10 seconds. The Vickers numbers are plotted against distance from the center of the weld in

[5] Recent tests made by another laboratory seem to indicate that cracking in gusset plates can be reduced by welding from the apex of the angle formed by the intersection of the tubes outward.

Fig. 11. It is claimed by the makers of the Vickers machine that for material of the hardness of chromium-molybdenum tubing the Vickers numbers correspond closely to the Brinell numbers.

The tube has a much lower Vickers number at a distance of one-half inch from the weld center. At this point it has approximately the same

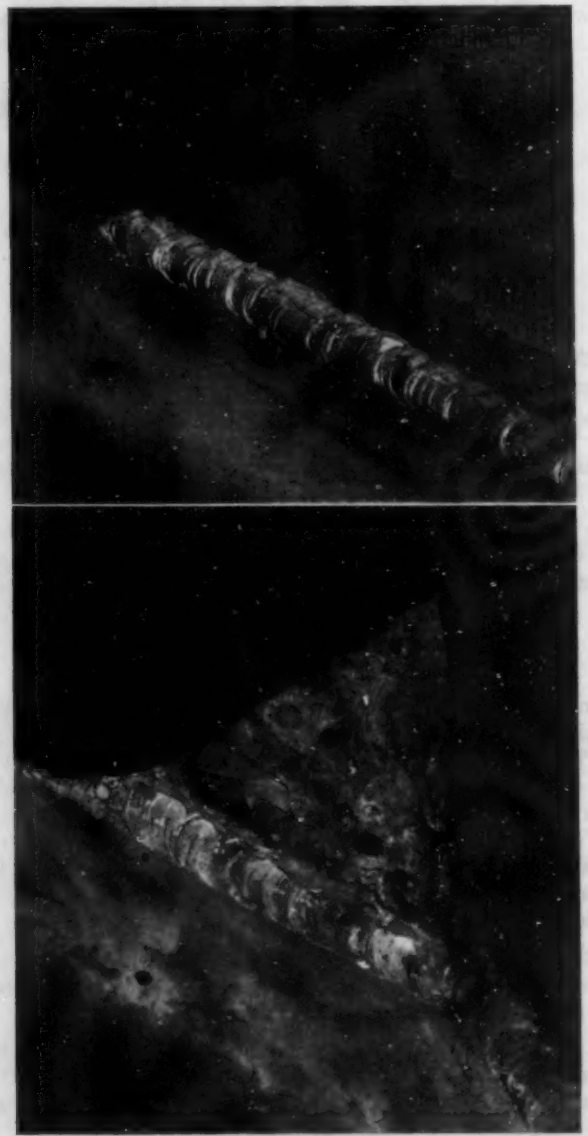


FIG. 9—CRACKS PRODUCED BY RESIDUAL STRESSES IN JOINTS AFTER COOLING. UPPER, IN SPECIMEN 753; LOWER, IN SPECIMEN 851

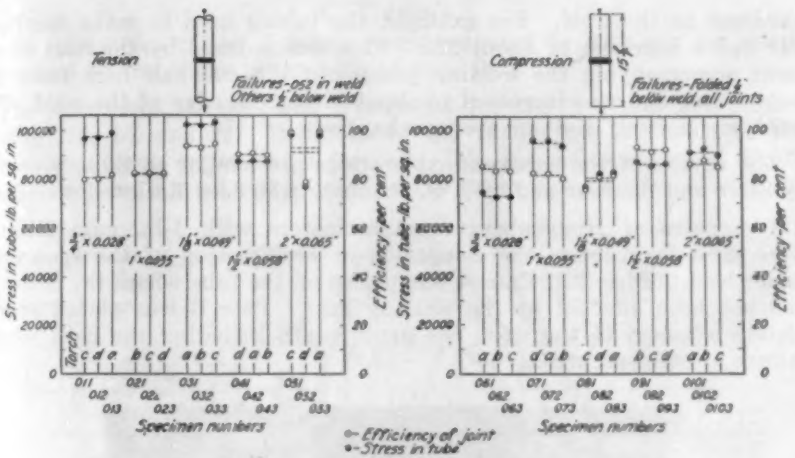


FIG. 10—MAXIMUM STRESSES AND EFFICIENCIES OF BUTT JOINTS

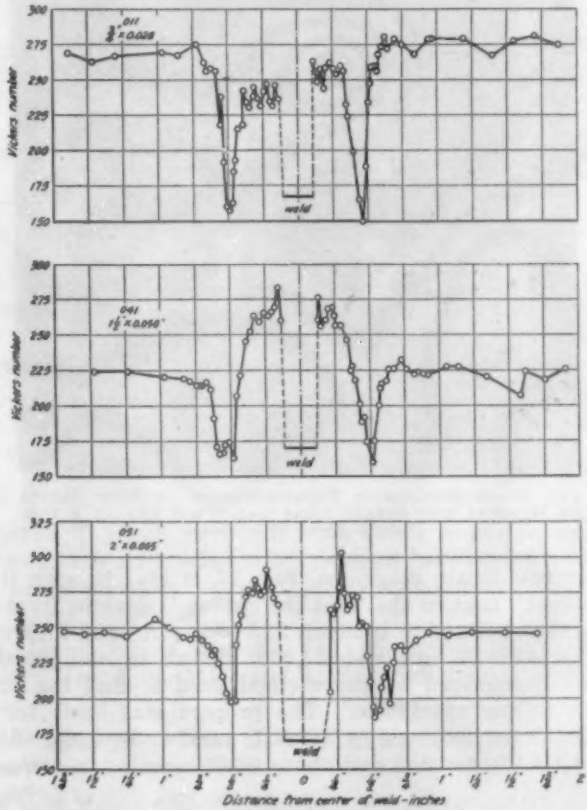


FIG. 11—HARDNESS EXPLORATIONS OF BUTT JOINTS

hardness as the weld. For example, the tubing used to make specimen 041 had a hardness of about 225. This was reduced by the heat treatment accompanying the welding process to 160, one-half inch from the weld center and was increased to about 280 at the edge of the weld. The weld metal itself had an average hardness of 170.

The results of the hardness explorations are similar to those reported by Sisco and Boulton[6] and by J. B. Johnson,[7] who used Rockwell machines.

Two pairs of Huggenberger extensometers with 1-in. gage lengths were used to measure the elongation or compression of the specimens under load. (Fig. 12.) Pair A was placed on the tube where the material had not been affected by the welding heat. Pair B was placed immediately adjacent to the weld, the gage length including the zone where failure usually occurred.

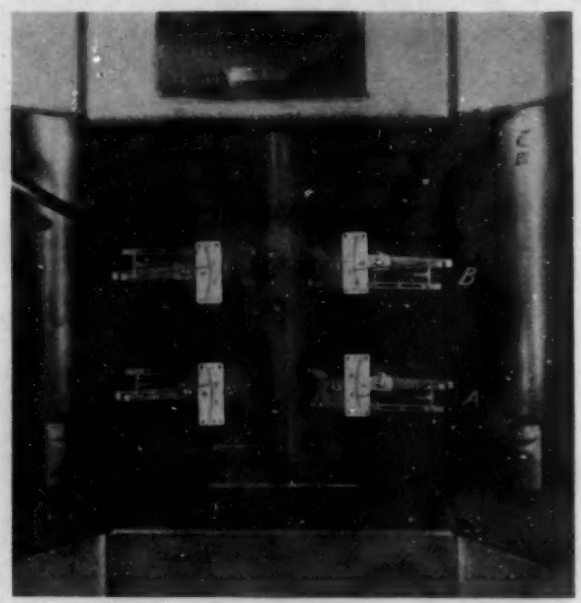


FIG. 12—HUGGENBERGER EXTENSOMETERS ON BUTT JOINTS TO MEASURE THE STRAIN NEAR THE WELD AND AT A DISTANCE FROM THE WELD

From the stress-strain diagrams, Fig. 13, it may be seen that for the 1-inch gage length next to the weld the curves B deviate from a straight line at a low stress, varying between 22,000 lb./in.^{2} and 27,000 lb./in.^{2} in tension and 22,000 lb./in.^{2} and 34,000 lb./in^2. in compression. This deviation was determined by the method used to find the proportional limit for the tubing specimens. The proportional limit for curves A checked with the values given in Table I, varying between 45,000 lb./in.^{2} and 60,000 lb./in.^{2} in tension and above 60,000 lb./in.^{2} in compression.

[6] Welding Steel Tubing and Sheet with Chromium-Molybdenum Welding Wire. Trans. A. S. S. T., vol. 8, No. 5, p. 589, November, 1925.
[7] Airplane Welding, p. 155, Goodheart Willcox Co. (Inc.), Chicago, Ill.

2. *T Joints*

The efficiencies of the T joints were computed by dividing the maximum load by the ultimate strength of tube B.

The maximum stresses and efficiencies for the T joints are plotted in Fig. 14, 15, and 16. Locations of the failure are indicated on the drawings. Thus, in loading I for joint 111, Fig. 14, a stress of 25,000 lb./in.^{2} in tube B produced a crack in the lower side of tube A adjacent

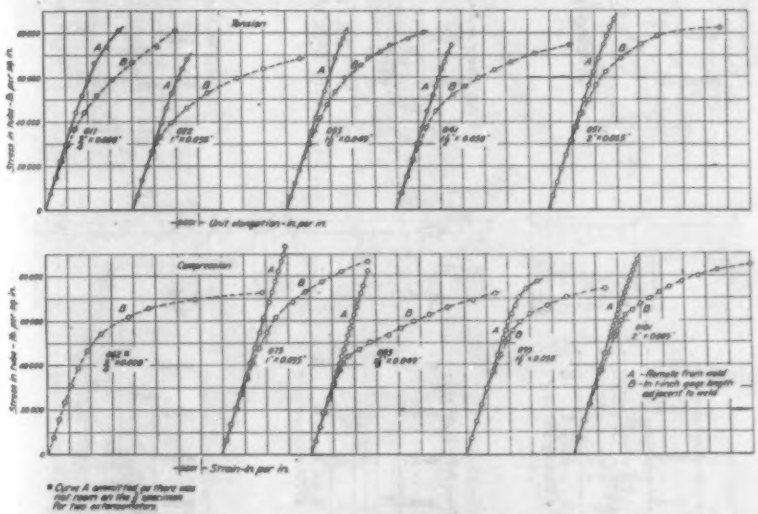


FIG. 13—STRESS-STRAIN DIAGRAMS FOR BUTT JOINTS IN TENSION AND COMPRESSION

to the weld. The permanent deflection was 0.067 in. and the efficiency of this joint was 18 per cent. In loading II at a stress of 73,000 lb./in.^{2} in tube B tube A reptured along the edge of the weld. The efficiency was 54 per cent.

Where it is believed that the strength in loading II was seriously lowered as a result of loading I, the value is plotted but not averaged with the others.

a. Loading I

Unreinforced T joints in which both tubes were the same diameter (120, 140, and 160) gave efficiencies ranging between 11 and 14 per cent in loading I. As would be expected, joints with the smaller tension members gave higher efficiencies.

Inserted plates (joints Nos. 230, 240, 250, 2230, 2240, and 2250) and straps (joints Nos. 3100, 3110, and 3120) produced very slight increases in efficiency.

Welding a triangular gusset plate in the angles formed by the intersection of the tubes increased the efficiency according to the size of the plate. Joint No. 430 had an efficiency of 12 per cent, practically no increase over the unreinforced joint which was 11 per cent. Joints Nos.

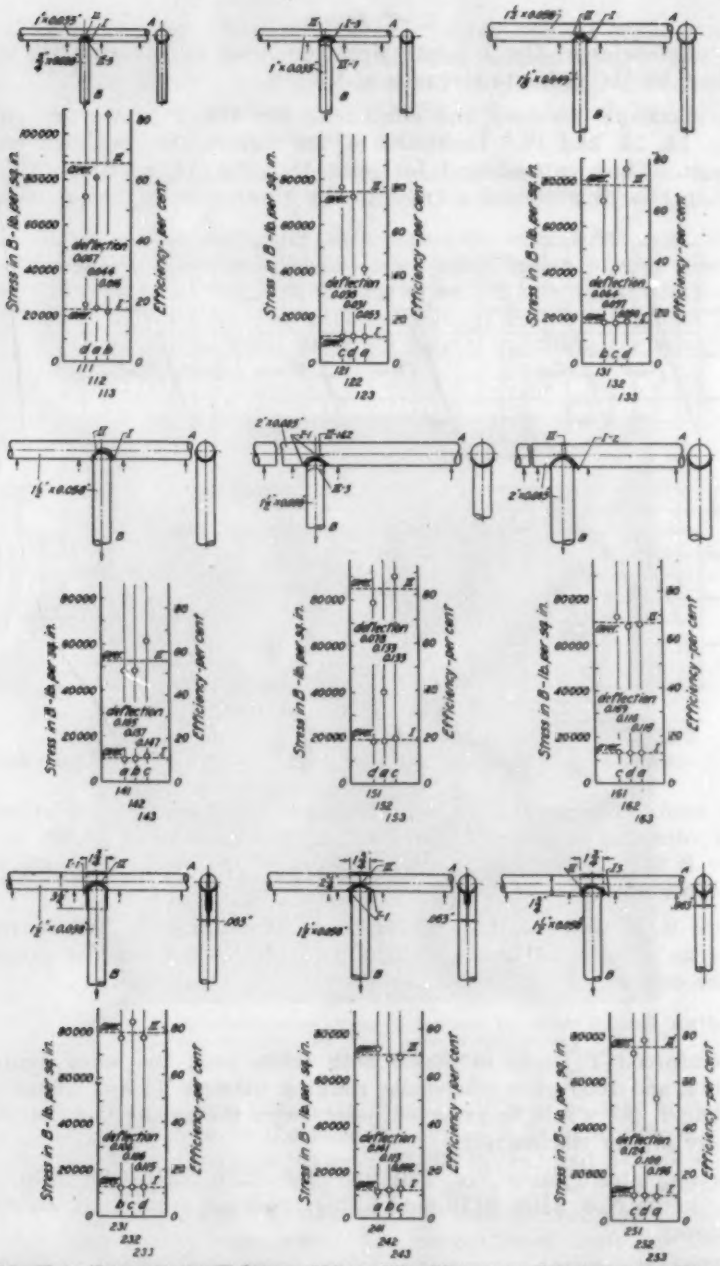


FIG. 14—TEST RESULTS FOR T JOINTS 110 TO 250. MAXIMUM STRESSES AND EFFICIENCIES HAVE BEEN PLOTTED ON THE SAME GRAPH. FOR EXAMPLE, IN JOINT 111, THE MAXIMUM STRESS IN LOADING I WAS 25,000 LB./IN.² TENSION IN TUBE B FROM THE STRESS SCALE ON THE LEFT SIDE OF THE GRAPH. THE PLOTTED POINTS ALSO INDICATE EFFICIENCY AND ON THE RIGHT SIDE, JOINT 111 IS SEEN TO HAVE AN EFFICIENCY OF 18 PER CENT IN LOADING I. THE PERMANENT DEFLECTION AT MIDSPAN WAS 0.067 INCH. IN LOADING II THE JOINT FAILED AT A STRESS OF 73,000 LB./IN.² ITS EFFICIENCY IN LOADING II WAS 54 PER CENT

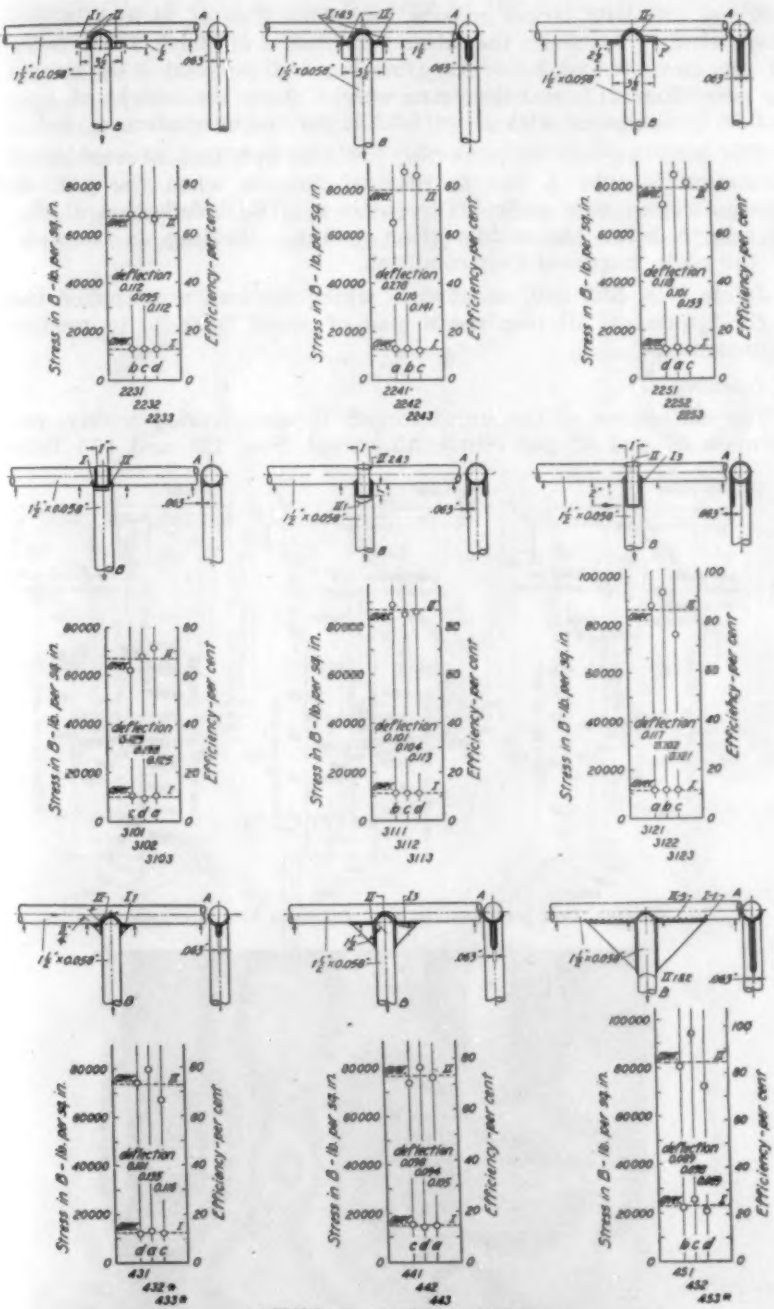


FIG. 15—TEST RESULTS FOR T JOINT 2230 TO 450

440 and 450, with larger gussets, had efficiencies of 14 and 24 per cent, respectively. Although the latter joint has a strength about twice that of the unreinforced joint, the time required to weld it is seven times as long (Fig. 21), and the extra weight above the weight of the tubes is 0.56 lb. compared with about 0.02 lb. for the unreinforced joint.

The large gussets of joint No. 450 also produced a considerable deformation in tube A due to residual stresses when the joint cooled. These stresses were sufficient to cause a 1/16-in. deflection of the ends of tube A below the middle after cooling. Welding on one side only of the plate improved this condition.

Joints Nos. 530, 560, and 590 in which the load was applied through a rigid terminal all required a load of about 3400 lb. to produce the permanent set.

b. Loading II

The efficiencies of the unreinforced T joints varied widely, ranging between 56 and 82 per cent. All except Nos. 121 and 153 failed by

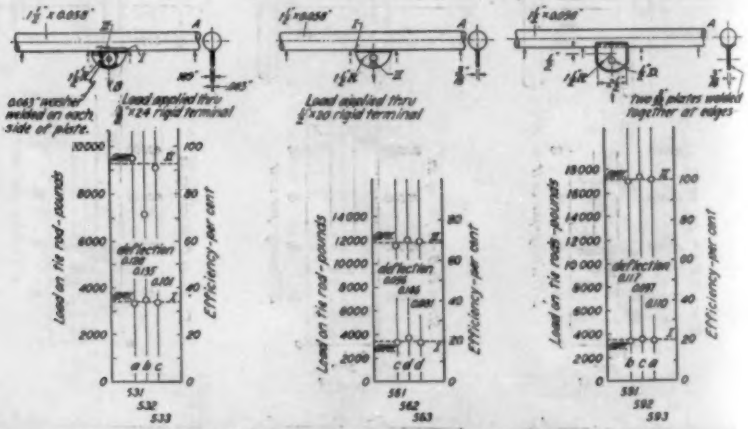


FIG. 16—TEST RESULTS FOR LUG T JOINTS 530, 560, AND 590

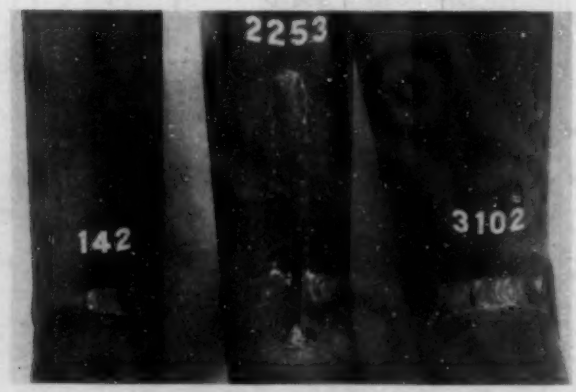


FIG. 17—TYPICAL FAILURES OF T JOINTS IN LOADING I

rupture of the A tube around the edge of the weld. Nos. 121 and 153 failed in tube B below the weld.

The joints reinforced by inserted gussets (Nos. 230, 240, and 250) had average efficiencies of 78, 69, and 74 per cent, respectively. The strength apparently did not depend on the depth of the gusset. All failed in tube A by rupture around the weld and by crushing around the plate at the top.

Joints having a wider gusset inserted in tube B only and welded to both tubes had about the same efficiency, 67 per cent for No. 2230 and 78

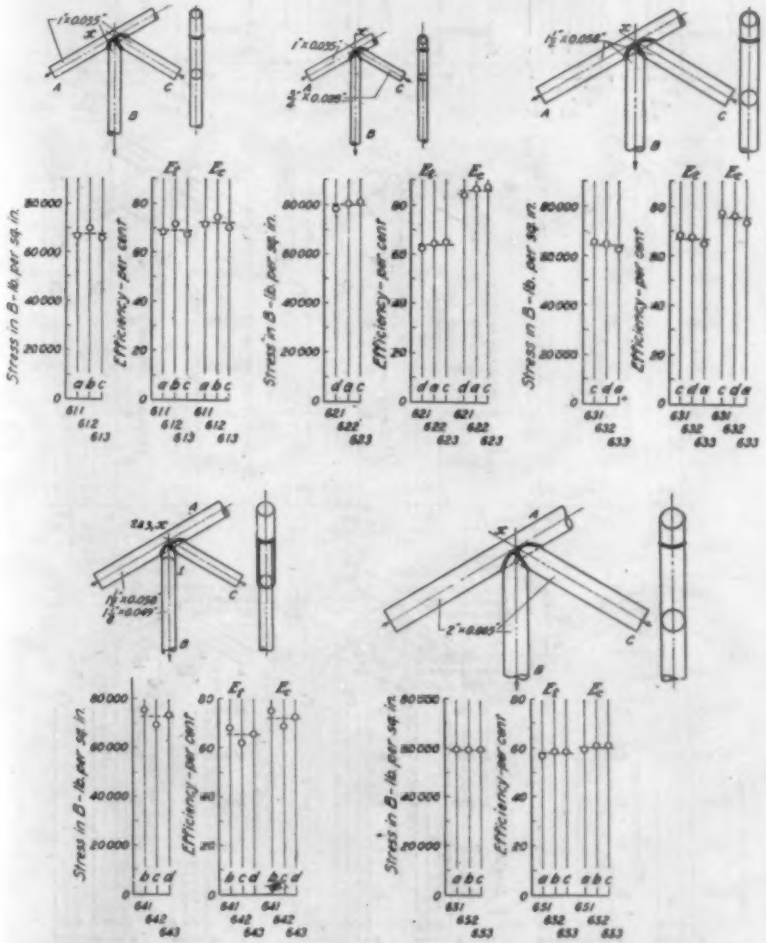


FIG. 18—TEST RESULTS FOR LATTICE JOINTS 610 TO 650. THE STRESS AND EFFICIENCIES HAVE BEEN PLOTTED SEPARATELY FOR THE LATTICE JOINTS. FOR EXAMPLE, SPECIMEN 611 FAILED AT A STRESS OF 67,000 LB./IN.² IN TUBE B. THE TENSILE EFFICIENCY, E_t, WAS 68 PER CENT AND THE COMPRESSIVE EFFICIENCY, E_c, WAS 72 PER CENT

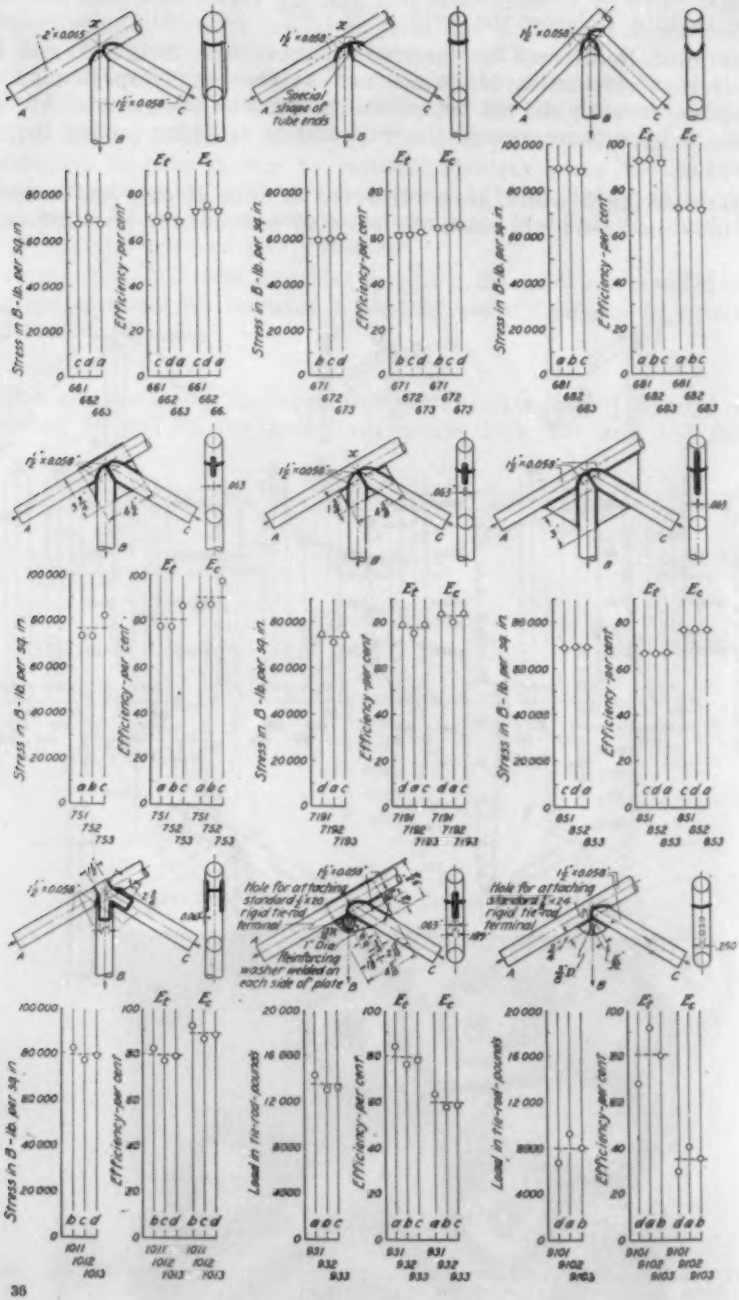

Special shape of tube ends
Hole for attaching standard 1/4 20 rigid tie-rod terminal
1" Dia. Reinforcing washer welded on each side of plate
Stress in B-lb. per sq. in.
Efficiency-per cent
Load in tie-rod-pounds

FIG. 19

per cent for Nos. 2240 and 2250. It is apparently of no advantage to make the depth of the gusset greater than 1½ in. (No. 2240).

Of the joints reinforced by a strap, No. 3110 had the highest efficiency, 87 per cent. This was also the highest for all the T joints. No. 3100 was weakened by the ends of the strap being too near the joint. A strap extending 1 in. below the top of tube A is obviously long enough.

Joints reinforced by triangular gussets not inserted gave average efficiencies of 73 per cent for No. 430 having the small gusset to 84 per cent for No. 450 with the largest plates. The average efficiency of Nos. 432 and 433, which were welded on one side of the gusset plate only, was

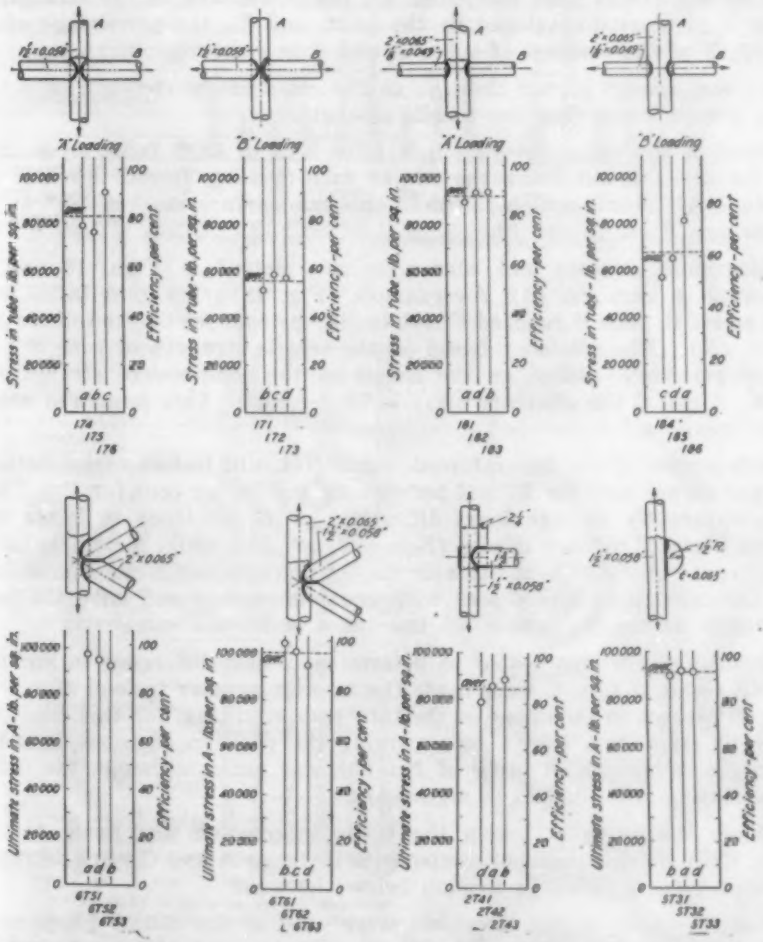


FIG. 20—TEST RESULTS SHOWING REDUCTION IN TENSILE STRENGTH FOR VARIOUS JOINTS. MAXIMUM STRESSES AND EFFICIENCIES ARE PLOTTED. FOR EXAMPLE, IN SPECIMEN 174 TUBE A WHEN LOADED IN TENSION FAILED AT A STRESS OF 80,000/LB./IN.², WHICH WAS 77 PER CENT OF ITS TENSILE STRENGTH

about the same as the efficiency of No. 431, which was welded on both sides. Joint No. 453 had an efficiency somewhat lower than the average and failed in tube A by tearing out of the gusset, starting on the unwelded side. The two that were welded on both sides of the gusset, Nos. 451 and 452, failed in tube B below the gusset.

Efficiencies of the lug joints were based on the strength of the tie-rods. Nos. 531 and 533 failed by the plate pulling out of tube A. The low efficiency of No. 532 apparently was caused by a crack in the plate. In No. 560 the pin sheared out of the plate. In No. 590 the tie-rod failed in tension.

3. *Lattice Joints*

Two efficiencies were computed, E_t, the percentage of the strength of tube B in tension developed by the joint, and E_c, the percentage of the strength of the weakest of tubes A and C in compression.

E_c was always higher than E_t as the compressive strength of a tube was always lower than the tensile strength.

Most of the unreinforced joints (Nos. 610 to 680) failed by collapse of the tubes at the joint, the end of tube C being forced into the wall of tube A. Joints which failed in this manner are marked "X" on the drawings, Figs. 18 and 19.

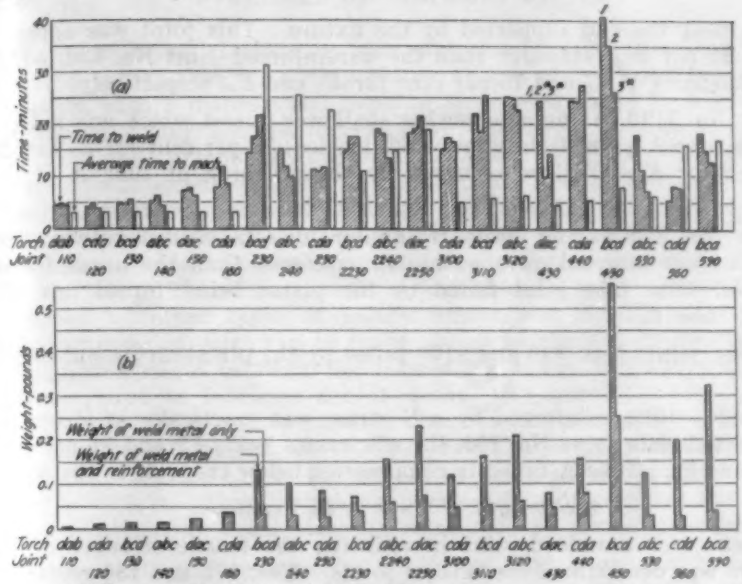
Maximum stresses and efficiencies are plotted in Figs. 18 and 19. Looking at joint No. 611, for example (Fig. 18), this joint failed when the stress in tube B reached 67,000 lb./in.^{2} by collapse of the tubes at the joint (X). The efficiency based on the tensile strength of tube B (E_t) is 68 per cent. Based on the lowest of the compressive strengths of tubes A and C the efficiency (E_c) is 72 per cent. This joint was welded with torch "a."

Efficiencies of the unreinforced joints Nos. 610 to 660 varied between 58 and 68 per cent for E_t and between 60 and 76 per cent for E_c. There was apparently no significant difference in the efficiency in joints with tubes B and C reduced in size (Nos. 620, 640, and 660). A 60 deg. lattice joint could probably be made with the tension member B reduced at least 10 per cent in wall thickness with equal diameters and have the same strength as one in which all the tubes were the same size.

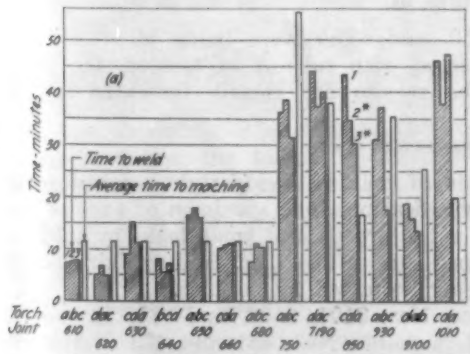
Joint No. 670 was tested to determine if any difference in strength would result if tube C were made the tension member instead of tube B. The difference in the shape of the tube ends resulting, for this condition, may be seen from Fig. 5 by reversing the position of tubes B and C. A slight advantage in favor of No. 630 was noted, although the difference may be too small to be significant.

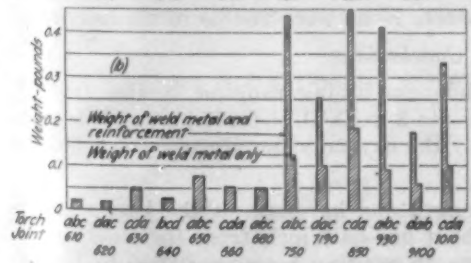
When the angle at which the tubes intersected was made 45 deg. (No. 680) the compression components in tubes A and C were decreased so that tube B failed in tension below the weld.

Similar types of reinforcement were used in the lattice joints as in the T joints. No. 750, in which an inserted gusset plate was used for reinforcement, was the strongest, the tensile efficiency, E_t, being 80 per cent and the compressive efficiency, E_c, 90 per cent. Failure occurred in


(a)
Time - minutes
Time to weld
Average time to mach.
1
2
3
(2*)*
Torch abab cdca bcd abc dac cdca bcd abc cdca bcd abc dac cdca bcd abc dac cdca bcd abc cdcd bca
Joint 110 120 130 140 150 160 230 240 2230 2250 3100 3110 3120 430 440 450 530 550 590
(b)
Weight - pounds
Weight of weld metal only
Weight of weld metal and reinforcement
Torch abab cdca bcd abc dac cdca bcd abc cdca bcd abc dac cdca bcd abc dac cdca bcd abc cdcd bca
Joint 110 120 130 140 150 160 230 240 2230 2250 3100 3110 3120 430 440 450 530 550 590

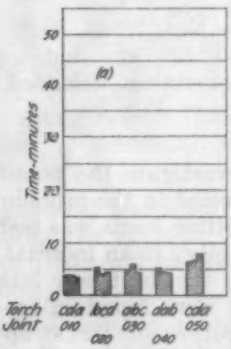
(a) Time required to machine and weld T-joints.
(b) Weights of weld metal and reinforcent in T-joints (average of three specimens)

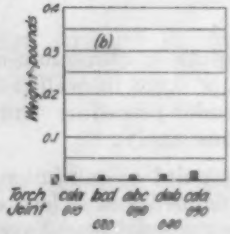

(a)
Time - minutes
Time to weld
Average time to machine
1
2*
3*
Torch abc dac cdca bcd abc cdca abc abc dac cdca abc dab cdca
Joint 610 620 630 640 650 660 680 750 7190 850 930 9100 1010


(b)
Weight - pounds
Weight of weld metal and reinforcement
Weight of weld metal only
Torch abc dac cdca bcd abc cdca abc abc dac cdca abc dab cdca
Joint 610 620 630 640 650 660 680 750 7190 850 930 9100 1010

* Gusset plate welded on one side only. Weights of specimens welded on both sides are plotted.

(a) Time required to machine and weld lattice joints.
(b) Weights of weld metal and reinforcement in lattice joints.





(a) Time required to weld butt joints.
(b) Weights of weld metal in butt joints.

FIG. 21.—TIME REQUIRED TO MACHINE AND WELD JOINTS; WEIGHTS OF WELD METAL AND REINFORCEMENT

tube A near the end supported by the fixture. This joint was approximately 20 per cent stronger than the unreinforced joint No. 630, which had efficiencies of 67 and 76 per cent for E_t and E_c, respectively.

Joint No. 7190 having a somewhat shallower gusset which was not cut through tube A gave slightly lower efficiencies; 78 per cent for E_t and 82 per cent for E_c. Failure occurred by the crushing of tube A at the joint.

Joint No. 850 having large triangular gussets welded between the tubes but not inserted gave no higher efficiency than the unreinforced joint No. 630. The joint failed by the plates being forced into the wall of tube B.

The lug joints Nos. 930 and 9100 failed by the pin shearing out of the gusset.

Joint No. 1010, reinforced by a U strap, was practically as strong as the inserted-plate joint No. 750, the efficiencies being 79 and 91 per cent for E_t and E_c. Tube A failed in compression below the weld to the strap.

4. *Strength of Tube A In Tension*

The effect of a welded joint in reducing the tensile strength of its members was determined for several joints. Nos. 170 and 180 represent the joining of two tubes B in an axis at right angles to a third Tube A. One set of three specimens was loaded along the axis of tube A and another set along the axis of tube B.

Joints Nos. 2T40, 5T30, 6T50, and 6T60 were made identical with Nos. 240, 530, etc., but were tested with tube A in tension, the other tubes remaining unloaded. The results are clearly indicated in the diagrams of Fig. 20.

5. *Pneumatic Test*

To investigate the possibilities of making welds tight against leaks as suggested in the procedure specifications, one specimen of each of the T and lattice joints was tested for the presence of small leaks by subjecting the tubes to an internal air pressure of 25 lb./in.^{2} and applying soapy water to the joint, any leaks being indicated by bubbles.

Leaks were found in specimens Nos. 3101, 3102, and 3103 in tube B at the corner of the strap and in joints Nos. 451 and 453 in tube B below the lower corner of the gusset. None were visible to the naked eye.

VI. *Conclusions*

For joints in chromium-molybdenum tubing ranging in size from ¾ in. O. D. × 0.028 in. wall thickness to 2 in. O. D. × 0.065 in. wall thickness, welded under procedure control by the oxyacetylene process, the following conclusions apply:

1. The point of minimum strength and hardness of the base metal is sharply defined and is located about one-half inch from the weld center. Here the material may have strength ranging between 80,000 to 100,000 lb./in.^{2} in tension and 70,000 to 95,000 lb./in.^{2} in compression and a Vickers number as low as 165.

2. For T joints loaded to high bending stresses near the joint it is

probably more satisfactory to gain strength by increasing the size of the tube rather than by adding plates, straps, etc. Where the joint is loaded in such a manner that bending stresses are kept to a low value, the efficiency may best be increased by welding a U strap around the joint, the ends extending at least 1 in. below the joint. The efficiency of an unreinforced joint was found to range from 55 to 77 per cent. Reinforcement by means of U straps increased the efficiency to 87 per cent. Strap-reinforced joints in which a tube is encircled by a circumferential weld are, however, subject to a reduction in the tensile strength of this tube. This reduction in strength is probably greater than is produced by other types of reinforcement and should be taken into consideration. A joint can be made almost as efficient by welding large triangular gussets between the interesting tubes, but the weight and time required to fabricate are excessive. An unreinforced T joint in 1½ in. × 0.058 in. tubing requires about eight minutes to fabricate and the weld metal weighs about 0.02 lb. The strap joint requires 28 minutes to fabricate, and the weight of the weld metal and reinforcement is 0.16 lb. These values are increased to 46 minutes and 0.56 lb. for a joint having equal strength reinforced by corner gussets.

3. The best reinforcement for the lattice joint is one which reinforces it against collapse of the tubes. This reinforcement may be either an inserted plate or a strap welded around the joint. Both methods increase the strength of the unreinforced joint about 20 per cent. The inserted-plate joint takes longer to fabricate and weighs somewhat more than the strap-reinforced joint. In the latter joint the tensile strength of the tube encircled by the strap is undoubtedly reduced. When gusset plates are used for reinforcement a decided gain in strength is obtained by inserting one plate in all tubes rather than welding several plates in the angles between the tubes. No reinforcement is necessary when the tubes meet at at angles of 45 deg.

4. Cracking is an important problem when gusset plates are used for reinforcement. A procedure for welding each type of joint should be worked out experimentally, and designs which can not be welded consistently without cracking should be discarded.

5. In using four representative oxyacetylene torches there was no indication that differences in the joint strength could be attributed to the torch.

6. Low-carbon rod apparently gives enough strength in the weld to cause the specimen to fail in the base metal for the majority of joints.

BUREAU OF STANDARDS, *Feb.* 6, 1930.

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Lengthening Rails by Butt Welding*

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IT will be unanimously agreed that rail joints are the principal enemies of economy and the most prolific trouble makers with which the railroad maintenance man has to deal.

The statement has frequently been made, and supported by accurate data, that battered rail ends are responsible for the removal of 85 per cent of all the rail which is renewed. It is further said that joint maintenance constitutes one of, if not the most, important expense in connection with maintaining roadbed in safe and serviceable condition.

FIG. 1—BUTT WELDING CREW IN TUNNEL

The rail joint being the weakest point in the track structure is responsible, in greater or less degree, for all of the troubles and expense to which track is subject. Even before the rail ends begin to show appreciable batter, the joints, even under a high standard of maintenance, are the prolific cause of trouble. Under traffic this weak point in the track structure first begins to give, resulting in the rolling and nosing of passing equipment. Such train action causes the track to become out of alignment and level. The first action taken by the maintenance man is the tamping up of his low joints. This results in increased solidity at the joint and sooner or later calls for the resurfacing of the entire stretch of track in order to maintain the surface to preserve the riding qualities of the track. It will be seen, then, that the joint is the primary cause of many of the difficulties with which it is not directly connected.

Over a long period of years, engineers have devoted their best efforts to the development of devices and methods which would improve the connection between one rail and the next, would decrease the excessive wear on rail ends and connections, and would effect economy in their mainte-

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nance. In spite of all the improvements which have been made, the rail joint still maintains its position as the leading trouble maker in track construction. It is, then, a fairly well established fact that whatever may be done to the rail joint, it cannot be reformed completely and as

FIG. 2—VEEING RAIL PREPARATORY TO BUTT WELDING FOR HIGHWAY CROSSING. AUTOMOBILE TRAFFIC WOULD NOT PERMIT DOING IN TRACK

long as it exists it will continue to take money out of the railroad treasury and put grey hair in the head of the railroad engineer.

Obviously, the only complete solution of the rail joint problem is the elimination of the joint.

In order to eliminate as many joints as possible, railroad engineers in recent years have gradually, but cautiously, increased the length of rails

from the original 30-ft. rail to 33, to 39, and later, in some few cases, to 66. The performance of these longer rails in track has been very closely watched and from all reports nothing but advantage has been gained from every step in the direction of longer rails.

It was at first feared that trouble would be experienced in taking care of contraction and expansion due to temperature variations in the longer

FIG. 3—COMPLETED BUTT WELDS FOR SAME ROAD CROSSING

sections of rail, but experience has proven that 66-ft. rail can be laid with the same expansion as 33-ft. rail without causing the least difficulty. However, there is an obvious limit to the length of rail which it is practical to roll at the mills and there is also a limit to the length of rail which can be advantageously handled in laying track. While it has been demonstrated that 66-ft. rail can, with proper equipment, be laid at less cost than can 33-ft. rail, it is apparent that any great increase beyond the 66-ft. length would introduce problems of transportation and handling which would be insurmountable.

The purchase of longer rails insures the elimination of a part of the joints. The 66-ft. rail would mean only one-half as many joints to the mile as the 33-ft. rail, but while this would mean much in the way of reducing the cost of mechanical joints and would materially improve the riding qualities of the track, it would leave a certain number of joints which would batter, calling for the frequent renewal of the rail and would merely reduce the cost of maintaining the mechanical joints in the same ratio that the longer rail bears to the shorter.

To accomplish the full advantage of joint elimination, it is, therefore, evident that the length of rail must be extended far beyond the limits placed by the rail mills and the steel gangs. The method which promises the accomplishment of this desirable result is the butt welding of rails by the process developed by our company. By this process, which has been in

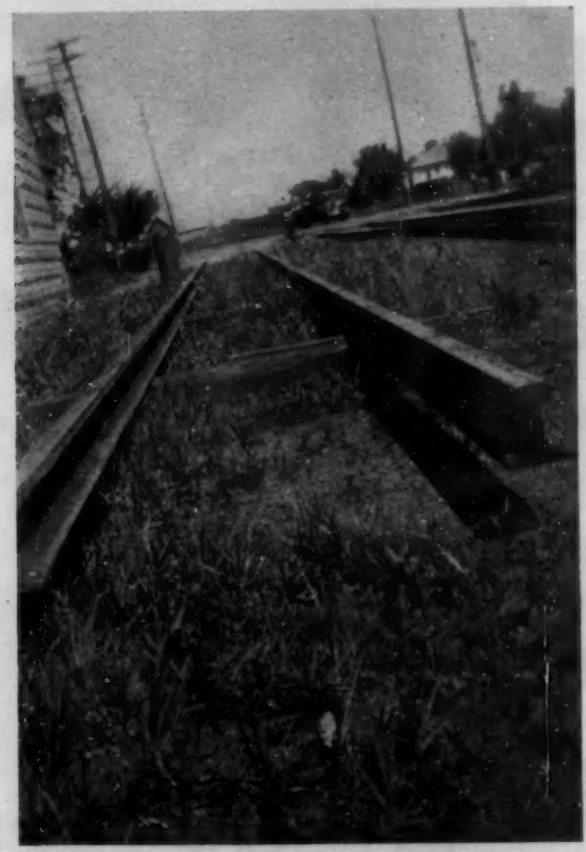

FIG. 4—BUTT WELDED RAILS READY TO PLACE IN TRACK AT ROAD CROSSING WHERE AUTOMOBILES WOULD NOT PERMIT DOING THEM IN TRACK

process of development over a period of years, it is possible to butt weld rails in track under traffic without interference with trains and at a cost which is infinitesimal as compared with the advantages to be secured. Up until the present time most of the butt welding which has been done under the supervision of The Oxweld Railroad Service Company has been of rail in tunnels, through road crossings, station platforms, on cinder pit tracks, on scale tracks and in similar locations where the maintenance of mechanical joints has been particularly difficult and expensive. The success of the work so far accomplished is attested by the fact that the butt welding of rails has increased more than 2000 per cent during the past five years. The results secured from the work already

done furnish conclusive proof of the feasibility of extending rail length by the butt welding procedure and the time has now arrived when the railroads should take full advantage of the possibilities of this process by extending the butt welding of rail to open track.

Progress along this line has reached a stage where butt welding is no longer an experiment. The work which has been done in this country

FIG. 5—DRAGGING IN A STRING OF BUTT WELDED RAIL WITH LOCOMOTIVE

speaks for itself and, if further evidence of the feasibility of connecting long stretches of rail is required, reference may be had to German practice where stretches of rail upwards of 1000 ft. have been welded together with highly satisfactory results. It has been conclusively demonstrated by the Germans that the problem of expansion and contraction may be ignored in its relation to long stretches of welded rail. The German engineers, whose thoroughness in such investigations is well appreciated, have found that all of the expansion and contraction resulting from temperature changes takes place in approximately 40 ft. at the end of any length of rail. This finding merely bears out the conclusions reached by our own engineers in their experience with the 33 and 66-ft. rails.

It should not be difficult for the railroad maintenance man to visualize the enormous advantages which would result from the elimination of

practically all the rail joints. Investigations made during recent years on several railroads have proved the serviceable life of rail in first position could be at least doubled if the wear at the rail ends could be eliminated.

Much has been accomplished during recent years along the lines of lengthening rail life by building up battered and chipped rail ends by the oxy-acetylene welding process. By this method the serviceable life of the rail may be substantially extended and the riding qualities of track

FIG. 6—CONTINUOUS RAIL THROUGH STATION. JOINTS ELIMINATED BY BUTT WELDING. CAUSED NO TROUBLE EVEN THOUGH RAIL IS NOT COVERED

may be maintained close to that of new rail. But even under the highest standards of maintenance wherein battered joints are built up as soon as they begin to show serious wear, there must be extended periods during which the riding qualities of the track are not 100 per cent and during which there is excessive wear upon the mechanical connections due to the slight batter which must exist for some time before it becomes serious enough to justify building up.

The use of this process of building up joints has saved the railroads many hundreds of millions of dollars, but still falls short of the promise of economy held out by the procedure of butt welding rails entirely to eliminate the joint. The entire elimination of the joint would, evidently, produce a track on which no batter occurred, so that the present expense of building up, the expense of maintaining mechanical joints, the expense of repairing equipment worn and damaged due to roughness caused by worn joints would be entirely eliminated from the railroad's operating expense.

FIG. 7—CONTINUOUS RAIL THROUGH ANOTHER STATION. JOINTS ELIMINATED BY BUTT WELDING

FIG. 8—CONTINUOUS RAIL THROUGH STREET CROSSING. ALL JOINTS ELIMINATED BY BUTT WELDING

FIG. 9—CONTINUOUS RAIL THROUGH THESE STATION GROUNDS. ALL JOINTS ELIMINATED BY BUTT WELDING

The butt welded rail joint not only promises to double the serviceable life of the rail, to entirely eliminate the cost of maintaining mechanical joints, but further guarantees the elimination of rail creeping which is at the present time a troublesome and expensive problem of all railroads. It is evident that rail solidly connected in stretches of 1000 ft. or more will present such resistance to the wave action set up by passing traffic that there will be no lateral movement of the rail on the ties whatever.

FIG. 10—ANOTHER EXAMPLE OF CONTINUOUS RAIL ON ALL TRACKS THROUGH STATION. JOINTS ELIMINATED BY BUTT WELDING. MAINTENANCE MEN WILL APPRECIATE WHAT THIS MEANS

The elimination of such creepage would in itself produce an economy which would no doubt more than pay the entire cost of the welded joints.

A further advantage of the continuous rail would be the provision of a perfect conductor for signal currents without the use of the expensive and troublesome bond.

A summary of the advantages which would result from the butt welding of rail in continuous stretches of such length as may prove most satisfactory includes the doubling of the service life of the rail, the entire elimination of joint maintenance, the prevention of creepage, the provision of a perfect electrical circuit for signals, the material reduction of wear on equipment, the substantial decrease in the resistance of the rail to train movements and the insurance during the entire life of the rail of smooth and noiseless track.

The railroads of today are facing the most serious competition which has been experienced at any time in their history. The development of highway, air and inland water transportation has already cut seriously into passenger revenues and further developments along these lines may

be expected to increase the difficulty which the railroads must experience in maintaining their competitive position in the transportation world. If the carriers by rail are to continue to successfully compete for traffic in passengers and commodities they must adopt every possible means for improving their service. Such improvements must take the form of increased speed for both passenger and freight service and must provide increased comfort for the traveler. Important steps have already been taken along the line of speeding up train movements and the provision of modernized equipment. In order to keep in step with these improvements it is absolutely essential that the track on which the trains move must also be improved and no railroad man will deny that the elimination of the rail joint gives greater promise of effecting such improvement than any other means which can be imagined.

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